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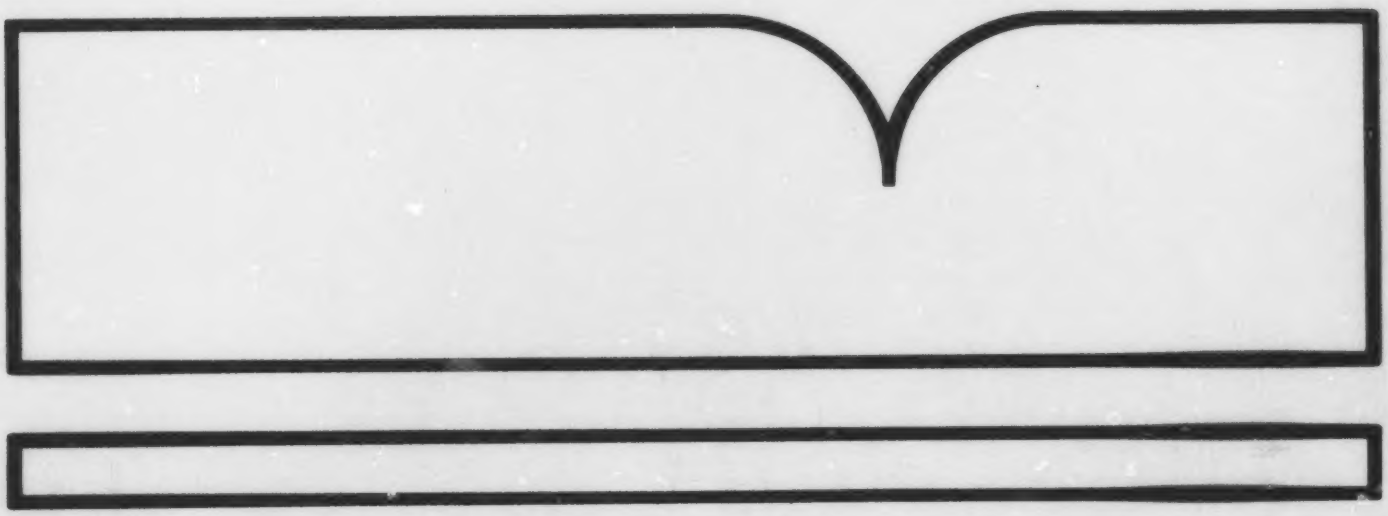
Sheet-Fed Paperboard Coating Technical Information Document for Technical Support in Development of a Revised Ozone State Implementation Plan for Memphis, Tennessee

Pacific Environmental Services, Inc., Durham, NC

Prepared for

Environmental Protection Agency, Atlanta, GA

Dec 85



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The document presents information on emissions of volatile organic compounds (VOC) from sheet-fed paperboard coating facilities. At present there is no control techniques guideline (CTG) document for the specific process. However, the CTG for VOC emissions from paper coating (EPA-450/2-77-008), which addresses web coating (continuous roll), is considered applicable to a sheet-fed operation. The primary differences may be in the method of feeding the paper product to the process line, the application of coating material, and removing the product from the process line. Much of the information on plant processes, description, emissions, etc., from the sole paperboard coating facility in Shelby in Shelby County is confidential. Therefore, information is presented on the general industry, emissions from paperboard coating facilities, general emission control techniques, and the costs of reducing emissions.

KEYWORDS: *Air pollution control, *Paperboards, *Point sources.

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SHEET-FED PAPERBOARD COATING

TECHNICAL INFORMATION DOCUMENT

FOR

TECHNICAL SUPPORT IN DEVELOPMENT
OF A REVISED OZONE STATE
IMPLEMENTATION PLAN FOR
MEMPHIS, TENNESSEE

Ms. Jill E. Thomas - Project Officer

U.S. Environmental Protection Agency

Region IV

EPA Contract No. 68-02-3887

Assignment No. 13

Pacific Environmental Services, Inc.
1905 Chapel Hill Road
Durham, North Carolina 27707

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DISCLAIMER

This final report was furnished to the U.S. Environmental Protection Agency by Pacific Environmental Services, Inc., Durham, North Carolina 27707, in fulfillment of Contract No. 68-02-3887. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the United States Environmental Protection Agency or of cooperating agencies. Mention of company or product names is not to be considered as an endorsement by the U.S. Environmental Protection Agency.

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GLOSSARY

Add-on control device	An air pollution control device such as a carbon adsorber or incinerator that reduces the pollution in an exhaust gas. The control device usually does not affect the process being controlled and thus is "add-on" technology as opposed to a scheme to control pollution through making some alteration to the basic process.
Application area	The area where the coating is applied by roll, rotogravure coater, or other coating applicator, including any tanks and/or apparatus containing feed materials conveyed to the coating applicator.
Capture	The containment or recovery of emissions from a process for direction into a duct which may be exhausted through a stack or sent to a control device. The overall abatement of emissions from a process with an add-on control device is a function both of the capture efficiency and of the control device.
Capture efficiency	The fraction of all organic vapors generated by a process that are directed to an abatement or recovery device.
Carbon adsorber	An add-on control device that uses activated carbon to adsorb volatile organic compounds from a gas stream. The VOC's are later recovered from the carbon, usually by steam stripping.

Casein	A white tasteless, odorless milk and cheese protein used to make plastics, adhesives, paints, and foods.
Catalytic incinerator	A control device which oxidizes VOC by using a catalyst to promote the combustion process. The catalyst allows the combustion process to proceed at a lower temperature, usually around 315°C to 427°C (600°F to 800°F) than a conventional thermal incinerator which would require 593°C to 760°C (1,100 to 1,400°F), resulting in fuel savings and lower cost incineration.
Coating	A protective or decorative film applied to a substrate. The term applies to any water-based, organic solvent-based, or solventless extrusion type material.
Coating line	The sheet-feeding area, application area, conveyor belt or roller, flashoff areas(s), drying oven(s), and stacking area.
Compliant coating	A coating whose volatile organic compound content does not exceed that allowed by regulation. Compliant coatings may be water base, low solvent (higher solids) or powder.
Control device efficiency	The ratio of the pollution reduction achieved by a control device and the pollution introduced to the control device expressed as a percentage.

Overall VOC emission reduction	The product of the capture efficiency and the control device efficiency gives an overall VOC emission reduction achievable for the process, expressed as a percentage.
Reformulated coating	A water base, high solids, or powder coating that may be used as a substitute for an existing coating.
Sheet-fed paperboard coating	Application of water-based, organic solvent-based or solventless extrusion type materials to paperboard sheets.
Solvent	A liquid used in a paint or coating to dissolve, disperse, or thin film-forming constituents and to adjust viscosity. It evaporates during drying and does not become a part of the dried film.
Substrate	The surface to which a coating is applied, such as paper, paperboard, or metal.
Thermal incinerator	A device for oxidizing waste material via flame and heat. This contrasts with a catalytic incinerator which incorporates a catalyst to aid the combustion.
Water-based coating	A coating which contains more than five weight percent water in its volatile fraction.
Web coating	Coating of fabric, paper, plastic film, metallic foil, metal coil or other products which are flexible enough to be unrolled from a large roll, coated by blade, roll coating or roto-gravure as a continuous sheet and, after cure, rerolled.

1.0 INTRODUCTION AND SUMMARY

This document presents information on emissions of volatile organic compounds (VOC) from sheet-fed paperboard coating facilities. At present there is no control techniques guideline (CTG) document for this specific process. However, the CTG for VOC emissions from paper coating (EPA-450/2-77-008), which addresses web coating (continuous roll), is considered applicable to a sheet-fed operation. The primary differences may be in the method of feeding the paper product to the process line, the application of coating material, and removing the product from the process line. Much of the information on plant processes, description, emissions, etc., from the sole paperboard coating facility in Shelby in Shelby County is confidential. Therefore, information is presented on the general industry, emissions from paperboard coating facilities, general emission control techniques, and the costs of reducing emissions. Sources of information include the CTG for paper coating, the VOC emissions inventory update for Shelby County, and discussions with VOC control equipment vendors, personnel from other paperboard coating facilities, solvent reclaimers, and EPA representatives.

The control measures described in this document represent the presumptive norm or reasonably available control technology (RACT) that can be applied to existing sheet-fed paperboard coating process lines. Reasonably available control technology is defined as the lowest emission limit that a particular source is capable of achieving by application of control technology that is reasonably available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical, source categories. It is not intended that extensive research and development be conducted before a given control technology can be applied to the source. However, short-term evaluation programs are considered an appropriate technology-forcing aspect of RACT.

The VOC's emitted are predominantly from organic materials used in the formulation of coatings that are applied to paperboard by roller or other coating applicator. An overall VOC emission reduction of 81 percent or better may be achieved by reformulation or by the installation of add-on control devices. In addition, use of good engineering and housekeeping practices in solvent handling can further reduce VOC emissions from coating application and cleanup.

The major provisions of the RACT recommendations are as follows:

1. Overall VOC emission reduction of 81 percent or better as calculated over a performance averaging period.

2. The use of good housekeeping and operational procedures to minimize VOC emissions as follows:

    - Perform a weekly visual inspection of pumps for evidence of leaks. Attach an identification tag to leaking equipment until repaired. Repair any equipment leak as soon as practicable within 15 calendar days,

    - Maintain a log of repairs including information on date of leak detection and description of the problem, dates and descriptions of any interim repair attempts, and date and description of final repair,

    - Maintain tight-fitting lids on containers of coatings and process and cleaning solvents,

    - Perform a daily visual inspection of all containers to ensure that lids are securely in place, and

    - Maintain a record with the repair log that confirms that the weekly pump inspections and daily container lid inspections are occurring.

2.0 PROCESSES AND POLLUTANT EMISSIONS

2.1 INDUSTRY DESCRIPTION[1]

Sheet-fed paperboard coating involves the application of water-based, organic solvent-based, or solventless extrusion type materials to paperboard sheets for a variety of decorative and functional purposes. Among the end products resulting from coated paperboard include decorated, coated, and glazed paper; book covers; office copier paper (zinc oxide coated); and laminated bread wrappers, skin pack, and blister pack.

Most organic solvent-based coating is done by paper-converting companies that buy paper from the mills and apply coatings to produce a final product. The paper mills themselves sometimes apply coatings, but these are usually water-based coatings consisting of a pigment such as clay and a binder such as starch or casein.[2] These water-based coatings are not normally sources of organic emissions.

Most companies that coat paper using organic solvents are listed in the U.S. Department of Commerce's Standard Industrial Classification (SIC) grouping 2641, Paper Coating and Glazing. This group includes establishments primarily engaged in manufacturing of coated, glazed, or varnished paper or paperboard from purchased paper stock.[3]

There are approximately 800 plants nationwide where paper coating operations occur. This number, however, includes paper, plastic film, and metallic foil coating.[4] The number of sheet-fed paperboard facilities has not been estimated. The range of sizes and the "typical" parameters for sheet-fed paperboard coating facilities are difficult to estimate. Again, the CTG presented a range of 9 "typical" paper coating plants. Solvent emissions from an individual coating facility vary with the hours of operation, size, and number of coating lines. A plant may have only one or as many as 20 coating lines. Solvent usage for these plants ranged from 545 kilograms per day (kg/day) (1,200 pounds per day (lb/day)) for a plant with two coating lines to 25,000 kg/day (55,000 lb/day) for a plant with 20 coating lines. Solvent emissions for these plants ranged from 1,100 kg/day (500 lb/day) for a plant with one coating line controlled by an afterburner (96 percent control efficiency) to 18,600 kg/day (41,000 lb/day) for a plant with 20 coating lines controlled by carbon adsorption

(96 percent control efficiency), although all 20 lines were not controlled. Four of the nine plants were controlled by a carbon adsorber, one was controlled by an afterburner, and four did not use a VOC control device. Information on typical parameters or range of sizes for sheet-fed paperboard coating facilities is not available.

Although a survey of paperboard coating facilities has not been undertaken, a list of some facilities performing paperboard coating for packaging operations is contained in Appendix D.

2.2 PROCESS DESCRIPTION[1]

Figure 2-1 shows a typical sheet-fed paperboard coating line. Components generally include a sheet feeder where individual sheets of paperboard are fed onto the conveyer; a coating applicator, such as a roll coater; a drying oven; and a stacker where the coated sheets of paperboard are placed until they are transferred to a storage and packaging area.

The coating materials (as applied) may be premixed and may consist of organic resins, copolymers, or varnishes that are thinned, dissolved, or suspended in an organic solvent or solvent mixture (process solvents). (Note: Other solvents not used in the coating process may be used for cleaning equipment, conveyer belt, or other housekeeping purposes, as described in Section 2.3). The coating materials generally are hand carried to a working tank located next to the application area. The coatings are pumped from the working tank to the coating troughs located below the coating applicator. Sheets of paperboard are fed automatically to the coating applicator, generally a roll coater, that is immersed in the coating troughs and applies coating material. Excess coating drips into the troughs and is returned to the working tank for recycling back to the process. The coated paperboard is then conveyed through the oven. As the coated paper is oven dried, the VOC evaporates and is vented to the atmosphere, and the coating cures. Since the paperboard exiting the oven may not be completely dry, the paperboard is air dried along the conveyer before the coated sheets are stacked at the end of the conveyer. The sheets are kept in the stacker until they are transferred by forklift or other carrier to the storage and packaging area.

Ovens, either electric or gas fired, range from 6 to 60 meters (20 to 200 feet) in length, and they may be divided into two to five temperature zones. The first zone, where the coated paperboard enters the oven, is usually at a low temperature, about 43°C (110°F) VOC emissions are highest in this zone. Other zones have progressively higher temperatures that cure the coating after most of the solvent has evaporated. The typical curing temperature is 121°C (250°F), although in some ovens, temperatures of 204°C (400°F) are reached. This is generally the maximum because higher temperatures can damage the paper. Exhaust streams from oven zones may be discharged independently to the atmosphere or into a common header and sent to the atmosphere or to a VOC or particulate control device. The average exhaust temperature is about 93°C (200°F).

2.3 SOURCES OF VOC EMISSIONS

Potential sources of VOC emissions from paperboard coating operations are as follows:

- o application area (coater and troughs),
- o uncovered containers (working tanks of coating or process solvent, containers of cleaning solvent, etc.),
- o leaking pumps,
- o flash off area between application area and ovens,
- o ovens and vents,
- o evaporation beyond ovens,
- o transfer, storage, and mixing of process and cleaning solvents, and
- o solvents used for cleaning rollers, conveyer belt, etc.

2.3.1 Coating Line Emissions

2.3.1.1 Oven. The main source of VOC emissions from the coating line is the oven, where up to 90 percent of all VOC emissions (coating line, solvent handling, storage, and transfer) may occur. This number is based on a range of estimates that include VOC emissions from coatings, process solvents, and cleaning solvents that are assumed to be vented to the oven. The EPA estimates that about 70 percent of plantwide solvents used in a typical paper coating plant are emitted from the coating lines and that about 30 percent of solvent usage is attributed to other sources, such as cleaning equipment, solvent transfer, storage, and mixing operations.[1,6]

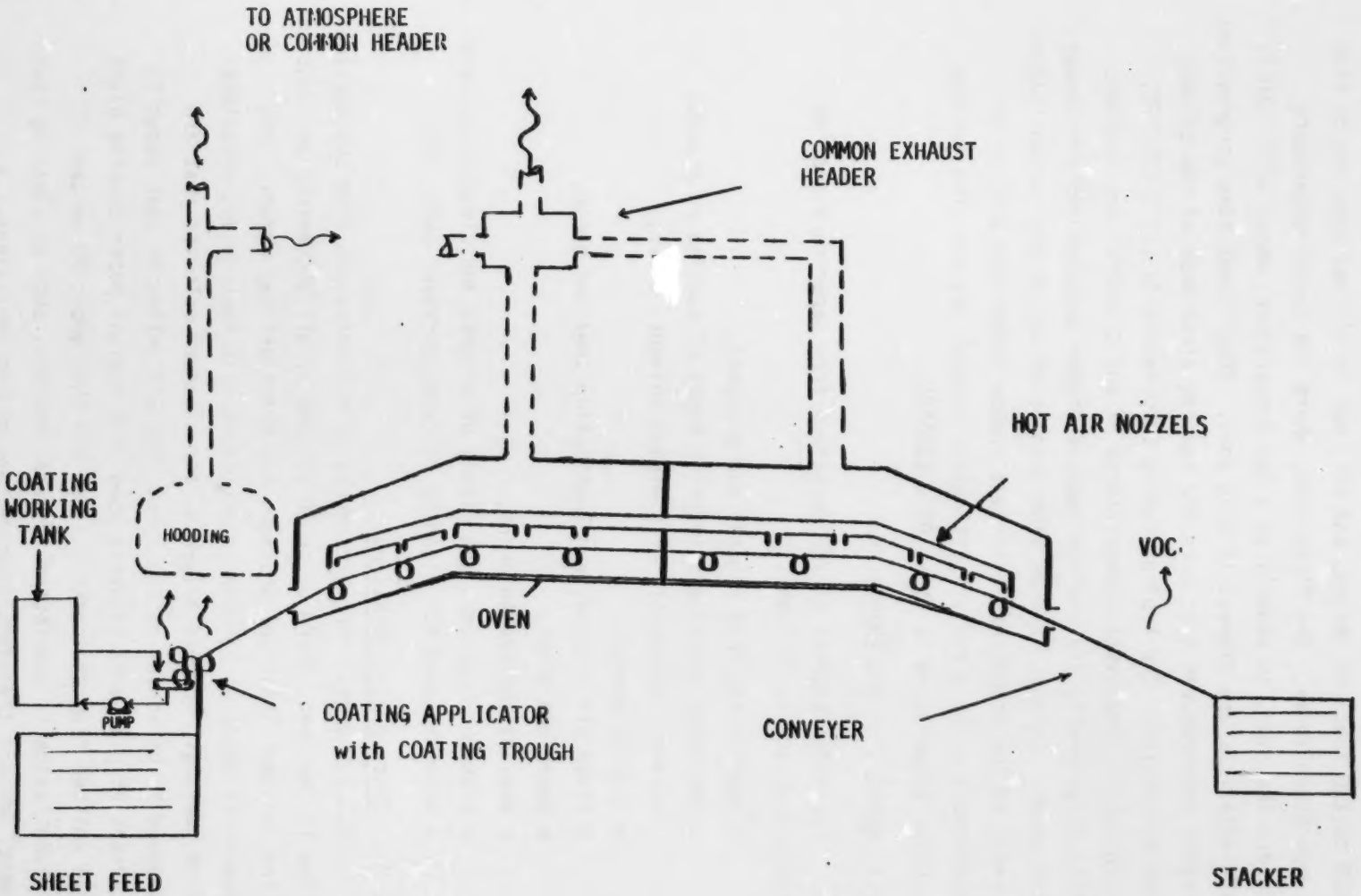

FIGURE 2-1. Schematic diagram of a sheet-fed paperboard coating line.

(Note: Some plants may vent solvent emissions from the application area and the oven exhaust through a common header.)[5]

There are a number of factors that affect the rate of process solvent evaporation and the capture of emissions, including ventilation systems, line speed, and length of zone between application area and ovens. It may be necessary to capture oven emissions by hooding the oven area to minimize worker exposure to these VOC emissions. Line speed and distance between application area and oven affect the rate of solvent evaporation. The longer the distance between application area and oven and the slower the rate at which paperboard is processed, the greater is the proportion of VOC emissions that occur prior to the oven, and the smaller is the proportion of VOC remaining on the paperboard to volatilize in the oven. For the purposes of calculating emission estimates, it is assumed that 90 percent of the total VOC emissions are captured by a ventilation system that directs the emissions to the oven. This assumes that all solvent emissions from cleaning rollers on-line are vented to the oven. The remaining 10 percent of total emissions includes losses from the application area and from solvent transfer, storage, and mixing operations.

2.3.1.2 Application Area. The application area is the next largest source of VOC emissions from the coating line (probably less than 10 percent of the emissions from the line). This includes sources such as the roll coaters and the coating troughs into which the rollers are immersed during application. Emissions from the application area are not typically controlled. It is important to note, however, that some plants install a hood over the application area to vent VOC emissions from the coating step in addition to venting VOC from the oven, as depicted in Figure 2-1.[5] In this configuration, the oven exhaust ducts and hooding vent over the application area merge to a common header that vents to the atmosphere from the roof. This ventilation system is used to reduce worker exposure to VOC emissions within the work environment without the use of a VOC control device to reduce emissions to the atmosphere.

2.3.1.3 Other Coating Line Emission Sources. After the paperboard has been coated, there is flashoff of process solvent from the product before it is dried in the oven. Flashoff emissions may also be captured by the hooding that is used to capture emissions from the application area discussed in the previous section. Part of the

process solvent remains with the finished product after it has cured in the oven. The coated paperboard may be dry enough at this point not to adhere to other sheets when stacked, yet still may be tacky. Some coaters estimate that 2 or 3 percent of process solvent remains in the product following oven drying.[1]

2.3.2 Other Sources

2.3.2.1 Solvent Transfer, Storage, and Mixing. VOC emissions may also occur from sources other than the coating line itself, but these emissions are relatively minor compared to process emissions. These include solvent transfer, storage, and mixing operations, particularly when containers of coating, process solvent, or cleaning solvent are not covered tightly or not covered at all. A potential emission source near the application area is the working tank containing the coating materials (diluted with process solvent) that are pumped to the coating troughs. If the tanks are uncovered and not closed tightly or the pumps are leaking, VOC may be released. Emissions of VOC may result from deterioration of seals on pumps used to transfer coatings from the working tank to the application area. A leaking pump in VOC service may emit 0.0494 kg VOC/hr/source (0.109 lb VOC/hr/source).[7]

2.3.2.2 Cleaning Practices. The use of solvents for cleaning rollers, ovens, and conveyer belts provides another source of VOC emissions. In some cases, process solvents used to thin coating materials may also be used as cleaning solvents. Some plants use cleaning solvents to remove debris and sludge from the conveyer belt, etc., without removing the rollers or other equipment from the line. Cleaning may occur during the process operation without necessitating a shutdown.[8] Other facilities completely shut down the process for cleaning.[9]

Paper coating facilities may use various methods of cleaning rollers and other coating line equipment. Equipment can be hand washed on-line with cleaning solvent; smaller operations are more likely to use this method. Rollers may be cleaned off-line by one of two methods.[10,11] (1) Dirty rollers may be placed in a cleaning tank containing a caustic water-based solution that is replaced periodically. The sludge that is formed at the bottom of the tank is shoveled out and disposed. (2) The Rencemann Washing Process® may be used to clean rollers and bearings. Solvent that is pumped through a large "washing

machine" cleans the dirty rollers that have been removed from the line. Dirty solvent is distilled and reused. The system is basically a closed process, although occasionally plant personnel "top off" the solvent. Heavy coating waste that is scraped off the rollers and other residues from the line that settle to the bottom of the Rencemann® are disposed in a hazardous waste drum; VOC emissions may occur from the machine at a rate of 2.7 to 4.5 Mg/yr (3 to 5 tons/yr) at a large plant operating 24 hours a day.[11] When dirty rollers are removed from the line for cleaning, a spare set of rollers is generally used to minimize shut-down time. Frequency of cleaning is highly variable and depends on the specific process. Some processes may require roller cleaning every 2 hours, while others may require no more than every 24 hours.[10] Quantities of solvents used for cleaning varies between about 2 percent[9] of the total solvent usage to about 10 percent.[9,12] VOC emissions can also occur from uncovered containers of dirty cleanup solvent and solvent-soaked wiping rags.

2.4 MODEL PLANTS

Two model plants were developed to characterize the range of emissions and other parameters for paperboard coating lines. The parameters for Model Plants A and B are presented in Table 2-1. The model plants are based on the use of organic coatings and solvents and no existing controls on the ovens. Each model plant is assumed to use a coating material mixed with two organic solvents, toluene and methyl ethyl ketone (MEK). Most of the toluene and MEK is used as process solvent to thin the coating material, and a small amount is assumed to be used on-line during process operation for cleaning rollers and other equipment. The solvent usage reported in Table 2-1 for Model Plants A and B includes solvent used for cleaning and solvent used in the process. It is assumed that a hood is in place over the oven to capture 90 percent of the VOC emissions from coating material, process solvents, and cleaning solvents. The amount of solvent emitted depends on such factors as coating and solvent usage and operating hours. For the purpose of this analysis, coating and solvent usage and operating hours vary between the model plants. The oven airflows and temperatures also vary. The oven temperature for Model Plant A is assumed to be typical for an electric oven used on a small paperboard coating line.

Model Plant B uses a gas-fired oven operating at a temperature that is considered typical for papercoating processes.[1] Exhaust gas temperatures were estimated based on a reduction in exhaust gas temperature of 11°C (20°F) from each oven. Model Plant A consists of one coating line and one drying oven. The coating line operates 1,800 hr/yr and uses about 50,000 l (12,000 gal) of coatings and solvents annually, while Model Plant B consists of five coating lines and one oven per line. Model Plant B operates nearly 24 hr/day, 250 days/yr, or 6,000 hr/yr, and uses about 780,000 l (207,000 gal) of coatings and solvents annually.

TABLE 2-1. MODEL PLANT PARAMETERS

Parameter	Model Plant A	Model Plant B
Production rate, Mg/yr (tons/yr)	900 (990)	15,000 (16,500)
Number of coating lines	1	5
Number of ovens[a]	1	5
Number of operating hours per year	1,800	6,000
Coating/solvent usage, l/hr (gal/hr) Coating[b]	14.4 (3.8)	71.9 (19)
Organic solvents[c]	11.7 (3.1)	58.7 (15.5)
Total uncontrolled emissions, Mg/yr (tons/yr)[d]	34.8 (38.4)	580 (640)
Exhaust gas flow rate, Nm^3/sec (scfm)	2.48 (5,250)	4.53 (9,600)
Oven (curing) temperature, °C (°F)	88 (190)[e]	149 (300)[f]
Exhaust gas temperature, °C (°F)	77 (170)	138 (280)

[a] One oven per coating line is assumed.

[b] Coating density assumed to be 7.9 lb/gal; 70% by weight as VOC.

[c] Solvents are a mixture of toluene and MEK; 90 percent of the solvent mixture is assumed to be used to thin the coating; 10 percent of the solvent mixture is assumed to be used for cleaning process equipment (e.g., rollers, conveyer belts). Based on solvent density of 7.2 lb/gal for toluene and 6.7 lb/gal for MEK. Weighted average density calculated to be 7.0 lb/gal based on solvent composition of 75% toluene and 25% MEK; 100% by weight VOC.

[d] Calculated as follows: (weight % VOC) x (total density) x (usage rate) x (operating hours per year).

Example calculation for Model Plant A:

$$\{[(0.7 \text{ lb VOC/lb coating})(7.9 \text{ lb coating/gal coating})(3.8 \text{ gal/hr})(1800 \text{ hr/yr}] + [(1.0 \text{ lb VOC/lb solvent})(7.0 \text{ lb/gal})(3.1 \text{ gal/hr})(1800 \text{ hr/yr})]\} \div 2000 \text{ lb/ton} = 38.4 \text{ ton/yr}.$$

[e] Typical for electric oven used on a small paperboard coating line.

[f] Typical for gas-fired oven used on a typical papercoating line (Reference 1).

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3.0 EMISSION CONTROL TECHNIQUES

VOC emissions from a paperboard coating line can be reduced by the use of reformulated coatings that have a low VOC content. In addition, add-on control techniques such as incineration and carbon adsorption can be used to control VOC exhausted through the drying oven and vent system. Control techniques for other sources (e.g., solvent storage, transfer, and mixing; cleanup operations; and equipment leaks) include general good housekeeping practices and visual leak detection and repair programs.

Section 3.1 discusses reformulated coatings, Section 3.2 discusses add-on control devices, and Section 3.3 discusses good housekeeping practices for the control of VOC emissions from a paperboard coating line.

3.1 REFORMULATED COATINGS[1]

VOC emissions can be reduced by using reformulated coatings, which can be accomplished by reducing the percentage of organic solvent using higher solids (low VOC) coatings or water-based coatings. A variety of reformulated coatings have been developed for coating paperboard. These coatings form organic resin films that can equal the properties of typical organic solvent-based coatings for some uses. Table 3-1 lists four types of reformulated coatings and the achievable VOC reduction for each one.

TABLE 3-1. ACHIEVABLE VOC REDUCTIONS USING REFORMULATED COATINGS IN PAPERBOARD COATING INDUSTRY[a]

Type of reformulated coating	Reduction achievable, %[b]
Water-based coatings	80-99
Plastisols	95-99
Hot melts	99+
Extrusion coatings	99+

[a]Reference 1.

[b]Based on comparison with a conventional coating containing 35 percent solids by volume and 65 percent organic solvent by volume.

3.1.1 Water-based Coatings

Water-based coatings have been used in coating paperboard. The most widely used types of water-based coatings consist of an inorganic pigment and a nonvolatile adhesive. Other water-based coatings have been developed in which a synthetic insoluble polymer is carried in water as a colloidal dispersion or an emulsion. This is a two-phase system in which water is the continuous phase and the polymer resin is the dispersed phase. When the water is evaporated and the coating cured, the polymer forms a film that has properties similar to those obtained from organic solvent-based coatings.[2]

3.1.2 Plastisols

Plastisols are low solvent coatings composed of a colloidal dispersion of a synthetic resin in a plasticizer. When the plasticizer is heated, the resin particles are solvated by the plasticizer so that they fuse together to form a continuous film. Plastisols usually contain little or no solvent, but sometimes the addition of a filler or pigment will change the viscosity so that organic solvents must be added to obtain desirable flow characteristics. When the volatile content of a plastisol exceeds 5 percent of the total weight, it is referred to as an organisol.

Paper is coated with plastisols to make products such as artificial leather goods, book covers, carbon paper and components of automobile interiors. Although organic solvents are not evaporated from plastisols, some of the plasticizer may volatilize in the oven. This plasticizer will condense when emitted from the exhaust stack to form a visible emission. Companies that use plastisols often have a small electrostatic precipitator to remove these droplets from the oven exhaust.

3.1.3 Hot Melt Coatings

Hot melt coatings contain no solvent; the polymer resins are applied in a molten state to the paper surfaces. All the materials deposited on the paper remain as part of the coating. Because the hot melt cools to a solid coating soon after it is applied, a drying

oven is not needed to evaporate solvent or to cure the coating. Energy that would have been used to heat an oven and to heat makeup air to replace oven exhaust is therefore saved. Considerable floor space is also saved when an oven is not used. In addition, the paper line speed can be increased because the hot melt coating cools faster than a solvent coating can dry.[2]

One disadvantage with hot melt coatings is that materials that char or burn when heated cannot be applied by hot melt. Other materials will slowly degrade when they are held at the necessary elevated temperatures.

Hot melts may be applied by heated gravure or roll coaters and are usually applied at temperatures from 65.5° to 232°C (150°F to 450°F).[2] The lower melting point materials are generally waxy type materials with resins added to increase gloss and hardness. The higher melting point materials form films that have superior scuff resistance, transparency and gloss. These coatings form excellent decorative finishes. One particular advantage of hot melts is that a smooth finish can be applied over a rough textured paper. This is possible because the hot melt does not penetrate into the pores of the paper.

3.1.4 Extrusion Coatings

A type of hot melt coating, plastic extrusion coating, is a solventless system in which a molten thermoplastic sheet is discharged from a slotted dye onto a substrate of paper, paperboard, or synthetic material. The moving substrate and molten plastic are combined in a nip between a rubber roll and a chill roll. A screw type extruder extrudes the coating at a temperature sometimes as high as 315°C (600°F). Low and medium density polyethylene are used for extrusion coating more than any other type resins.[3]

More than 260 extrusion coating lines now produce materials for paper, paperboard, and flexible packaging applications.[3] Hundreds of products are coated with extrusion coatings. Food packaging materials are often coated by extrusion coatings because a good moisture barrier can be formed. A well known extrusion-coated product is the polyethylene-coated milk carton.

3.1.5 Advantages and Limitations of Reformulated Coatings

Generally, use of an organic solvent has several advantages over use of reformulated coatings. (1) Organic solvents will dissolve organic resins that are not soluble in water; (2) their components can be changed to control drying rate; and (3) organic-based coatings show superior water resistance and better mechanical properties than some types of waterbased coatings. In addition, a wide variety of surface textures can be obtained using organic-based coatings.

Most of the reformulated coatings discussed in this section are currently being used for certain types of products, although organic solvent-based coatings are more widely used than reformulated coatings. In general, reformulated coatings are available for some papercoating applications. In fact, no fundamental problems are expected from reformulating conventional coatings (e.g., solvent-based, such as vinyl coatings) to high solids or low VOC coatings for use on papercoating lines. The feasibility of converting from conventional coatings to reformulated coatings depends on the type of equipment, viscosity of the coating mix, and coating solids content.[4] Continued research will expand the number of applications for these low VOC coatings. For example, vendor and company experience with the use of waterborne coatings for blister packaging applications varies. Appendix D summarizes the information gathered in the use of compliant coatings for blisterpack applications.

3.2 ADD-ON CONTROL DEVICES

Add-on control devices, such as thermal and catalytic incinerators and carbon adsorption units, can be used to control VOC emissions from paperboard coating operations. These control techniques can achieve between 90 and 98 percent emission reduction. Specifically, since most of the VOC emissions from the coating line and solvent handling, transfer, and storage are delivered to the oven (about 90 percent), the oven emissions can be exhausted directly to one of these control devices and, therefore, effectively reduce 81 to 88 percent of the total emissions. This range in overall VOC emission

reduction is based on capture and delivery of 90 percent of the VOC to the control device, which has an efficiency of between 90 and 98 percent.

3.2.1 Incineration

Incineration (thermal or catalytic) may be an applicable control device to reduce VOC emissions from paperboard coating operations. Figure 3-1 presents a diagram of an overall control scheme for venting oven emissions to a catalytic incineration system. The heat exchanger shown is used to boost the heat content of the waste gas and reduce supplemental fuel requirements. Section 3.2.1.1 discusses thermal incineration, while Section 3.2.1.2 discusses catalytic incineration.

3.2.1.1 Thermal Incinerators. The design and operation of thermal incinerators are influenced by operating temperatures, residence time, desired control efficiency, offgas characteristics and combustion air. Generally, operating temperatures are between 650°C (1,200°F) and 980°C (1,800°F) with a residence time of 0.3 to 1.0 second.[5] The combustion chamber is designed to maximize the mixing of the VOC stream, combustion air, and hot combustion products from the burner. This ensures that the VOC contacts sufficient oxygen while at combustion temperature to maximize combustion efficiency.

Additional parameters affecting the design and operation of thermal incinerators include the heating value and water content of the waste gas stream and the excess combustion air delivered to the incinerator. Generally, a waste gas with a heating value of less than 1860 kJ/scm (50 Btu/scf) will require supplemental fuel to maintain combustion, but these requirements may be reduced through use of a heat exchanger that boosts the energy content of the waste gas. Waste gases with a heating value between 1,860 and 3,720 kJ/scm (50 and 100 btu/scf) can support combustion but require supplemental fuel to ensure flame stability (avoid a burnout). Theoretically, waste gases with a heating value greater than 3,720 kJ/scm (100 Btu/scf) may not require any additional fuel, but experience has shown that 5,580 kJ/scm (150 Btu/scf) may be necessary to ensure proper incinerator performance without supplemental fuel.

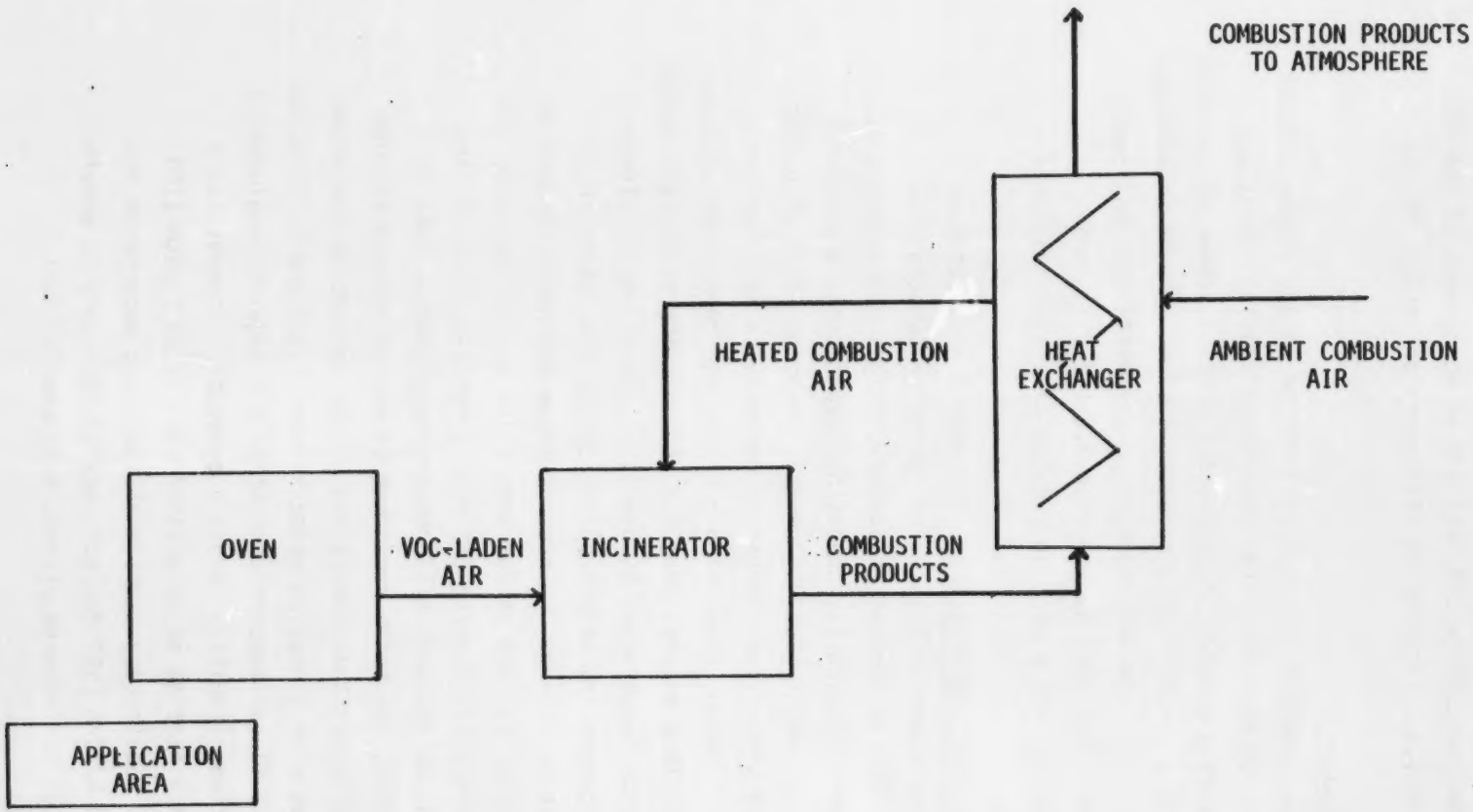

Figure 3-1. Schematic Diagram of Catalytic Incineration System With Heat Recovery.

Test results show that properly designed and operated thermal incinerators consistently achieve 98 percent VOC control efficiency under a variety of operating conditions: combustion chamber temperatures ranging from 700 to 1,300°C (1,300 to 2,370°F) and residence times between 0.5 and 1.5 seconds.[6,7]

3.2.1.2 Catalytic Incinerators. To control VOC emissions from dilute streams (i.e., having a low heat content), a catalytic incinerator might be a favorable choice over a thermal incinerator. The control principles and equipment used in catalytic incineration are similar to those employed in thermal incineration. The VOC-containing waste gas is heated to an appropriate reaction temperature, and oxidation of this stream is at active sites on the surface of a solid catalyst. The catalyst increases the rate of oxidation and allows the reaction to proceed at a temperature lower than that of thermal incinerators. Catalytic incineration is generally preferred to thermal incineration for controlling exhaust gases with a low VOC content because catalytic incineration requires less supplemental fuel than thermal incineration. A heat exchanger may be used to further reduce supplemental fuel requirements. Additionally, catalytic incineration may produce less NO_x than thermal incineration because of lower reaction temperatures and less excess air requirements. One company stated that they intend to install a catalytic incinerator on blisterpack coating lines in order to meet a State regulation of 0.35 kg VOC per liter coating (2.9 lb/gal).[8]

The operating temperature of a catalytic incinerator is typically 315°C to 650°C (600°F to 1,200°F), which is considerably lower than thermal incineration. Reaction may not occur below 315°C (600°F), and temperatures above 650°C (1,200°F) may shorten the catalyst life.[9] In addition, accumulation of particulate matter, condensed VOC's, or polymerized hydrocarbons on the catalyst may block the active sites and decrease control efficiency. Catalysts can also be contaminated by compounds containing sulphur, bismuth, phosphorus, arsenic, lead, antimony, mercury, zinc, tin, or halogens. Some vinyl coating materials cause catalyst damage and require a higher efficiency filtration system for its removal from the gaseous stream.[10]

The control efficiency of a catalytic incinerator is a function of many variables, including catalyst type, catalyst surface area, volume, and pore distribution, gas composition, uniformity of flow through the catalyst, oxygen concentration, and temperature.[9,11] The efficiency will decrease over time necessitating periodic catalyst replacement. This replacement time varies widely from less than 1 year to up to 10 years,[5] with an average life of between 3 and 5 years.[12]

A 1980 study of catalytic incineration by Englehard Industries indicated that control efficiencies ranged from 97.9 percent to 98.5 percent. These efficiencies represented control levels for carbon monoxide, methanol, dimethyl ether, and formaldehyde.[13]

3.2.2 Carbon Adsorption

Carbon adsorption has been used since the 1930's for collecting VOC emitted from paper and paperboard coating operations.[1] Most operational systems on paperboard coating lines were installed because solvent recovery and reuse made the adsorption system profitable. Pollution control has usually been a minor concern. Exhausts from several coating lines may be manifolded together to permit one carbon adsorption unit to serve several coating lines.

The typical carbon adsorption system is an activated carbon unit generally with two or more adsorption beds. One or more beds collect vapors while one bed is regenerated. During adsorption, hydrocarbons in the air stream penetrate the carbon particles and are retained. The ability of activated carbon to retain hydrocarbons depends on molecular size, vapor pressure, and temperature. Larger molecules are adsorbed more strongly than smaller ones, but are also more difficult to desorb. In general, methane and ethane, which are classified as non-VOC hydrocarbons, are too weakly adsorbed for carbon beds to be effectively used in their recovery, while molecules larger than octane are difficult to desorb. Hence, the effective range for the carbon bed is from propane to octane.

The bed can be regenerated by desorbing the hydrocarbons. This is done usually by increasing carbon bed temperature (steam injection) or by reducing the vapor pressure (inducing a vacuum). Bed regeneration is most commonly done by steam injection or indirect heating, but inducing a vacuum results in better regeneration of the bed. However,

this is generally more costly than steam injection. Carbon adsorption units can be over 90 percent efficient in controlling VOC emissions that are drawn into the carbon bed.[14,15]

Recovery of solvents after carbon adsorption is more successful with single than with multiple solvent processes. Many coaters using carbon adsorption, therefore, have reformulated their coatings so that only one solvent is required. According to plant personnel and equipment vendors, toluene, a widely used solvent for paperboard coating, is readily captured and decanted (gravity separation) by carbon adsorption systems, and recycled back to the process resulting in product savings.[14,16]

One potential problem associated with the application of carbon adsorption units to papercoating lines is the high amount of solids present in exhaust gases that reduce the life of the carbon bed and the collection efficiency of a carbon system. Some vinyl coatings may polymerize on the carbon bed.[17] To eliminate this problem, however, the carbon adsorption unit can be preceded by a particulate control device such as a fabric filter, which may trap an estimated 99+ percent of the solids before the particles reach the carbon bed. However, the size of the filter mesh required to collect the solids would depend on the specific compounds entering the filter (i.e., the smaller the particle size of the compound(s), the smaller the filter mesh). Several vendors noted potential problems with collecting resinous coatings or lacquers on a conventional fabric filter because of the small particle size of the resin and the low pressure drop across a conventional filter.[10,17,18,19] In this case, a special filtration system may be necessary to collect smaller particles.[10,17]

Another potential problem associated with carbon adsorption systems is the possibility of carbon bed fires when MEK is present in the system. Because of the potential for an isothermic reaction, the carbon beds should be cleaned well, and MEK should not remain in the bed for extended periods.[20] In addition, when MEK is present, the MEK may generate an acid which would need to be neutralized periodically by a buffer solution.[18,21]

The greatest obstacle to the economical use of carbon adsorption is that in some cases reusing solvent may be difficult. In many coating formulations, a mixture of several solvents is needed to attain

the desired solvency and evaporation rates. If this solvent mixture is recovered, it sometimes cannot be reused in formulating new batches of coatings. However, as noted above, toluene, a widely used solvent, would be easily captured and separated from a mixture of water-soluble solvents because it is relatively insoluble in water. In addition, if different coating lines within the plant use different solvents and are all ducted to one carbon adsorption system, then there may be difficulty reusing the collected solvent mixture. In this case, solvents can be separated by distillation. Separation of solvent mixtures by distillation is available technology that several papercoating plants are using.[1,16,22] One paper coating plant has been using such distillation procedures since 1934.[1] Distillation equipment can be expensive, yet cost effective in reducing VOC emissions. Figure 3-2 illustrates exhaust gas flow through a carbon adsorber, including recovery of toluene from a decanter and recovery of MEK after distillation.

3.3 GOOD HOUSEKEEPING PRACTICES

VOC emissions from transfer, storage, and mixing of coatings and process solvents, and from cleanup procedures can be minimized through the use of good housekeeping practices. Emissions of VOC occur during coating and process solvent transfer because of deterioration of seals on pumps used to transfer the materials from the working tank to the application area of the coating line. Some plants may repair leaking pumps when detected by sight or by smell, while others may allow pumps to continue leaking. Emissions of VOC from leaking equipment would be minimized if pumps and other equipment containing or contacting VOC were routinely checked for leakage and, if leaking, repaired as soon as practicable. EPA testing programs in chemical plants have found that the average leaking pump (in light-liquid service) emits 0.437 kg/hr (0.96 lb/hr) VOC. Repair of leaking pumps accomplishes about a 97 percent reduction in emissions or, correspondingly, a reduction of 0.425 kg/hr (0.94 lb/hr).[23] Therefore, for every day that a leaking pump is allowed to operate, about 10 kg (22 lbs) VOC would be released to atmosphere.

Emissions of VOC can be minimized by maintaining tight-fitting lids on all containers holding VOC, such as the coating working tanks and the cleaning solvent containers. The frequency, duration, and degree to which these containers are opened should be restricted to the minimum extent feasible.

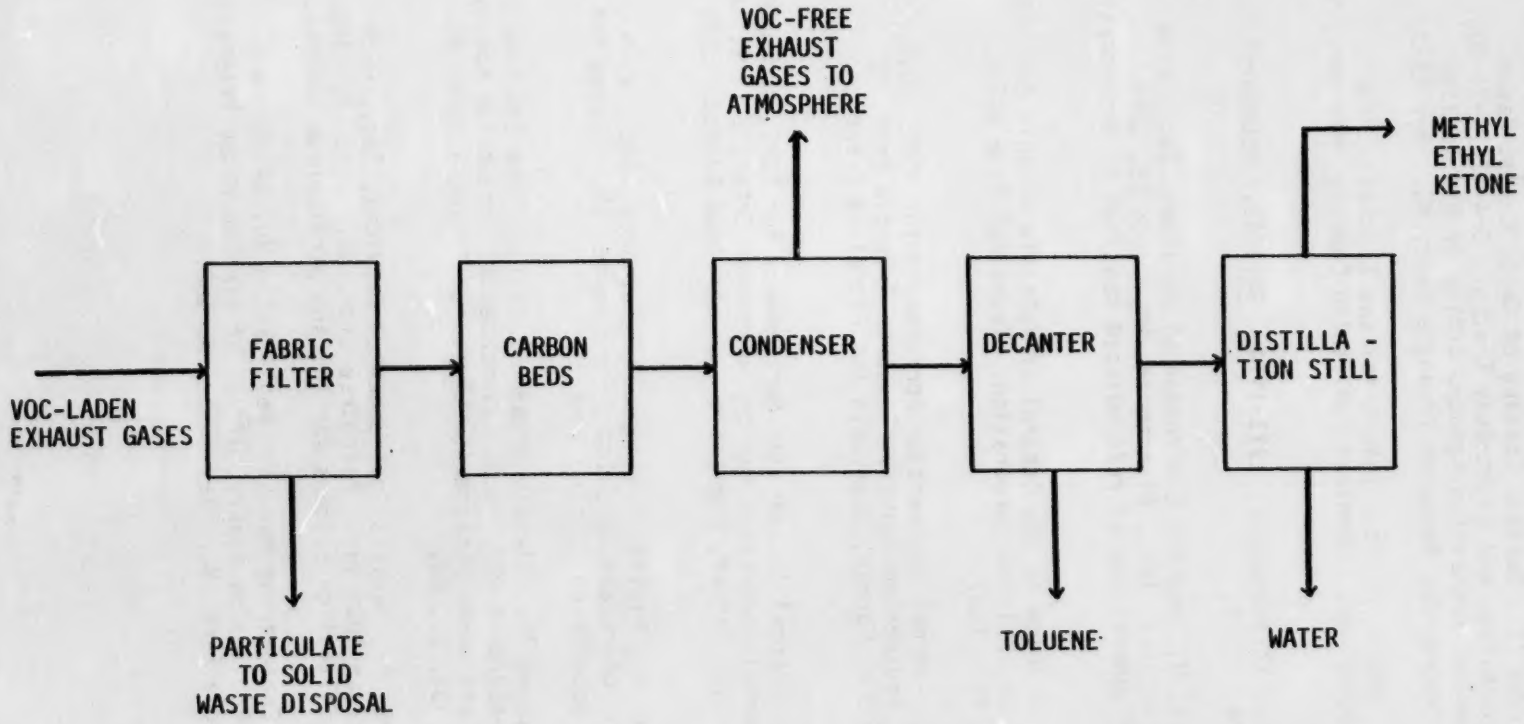

Figure 3-2. Schematic Diagram of Carbon Adsorption and Solvent Recovery System for Paperboard Coating.

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4.0 ENVIRONMENTAL ANALYSIS OF RACT

This chapter discusses the environmental and energy impacts that would result from implementing reasonably available control technology (RACT) for a sheet-fed paperboard coating line. The environmental analysis consists of primary impacts from air and water pollution and solid waste. There are no secondary impacts associated with RACT. Primary impacts are considered to be those impacts directly associated with application of RACT, while secondary impacts are only indirectly associated with application of RACT.

4.1 REASONABLY AVAILABLE CONTROL TECHNOLOGY

Reasonably available control technology for paperboard coating facilities located in Shelby County, Tennessee, is an overall VOC emission reduction of at least 81 percent. RACT may be achieved by the following methods: (1) A plant owner or operator may use substitute or reformulated coatings with reduced VOC content. VOC emissions resulting from the use of such coatings should be 19 percent or less of the average VOC emissions calculated over a base period. The testing period over which emissions are estimated when using reformulated coatings shall not exceed 24 hours; or (2) A plant owner or operator may use an add-on control technique, such as carbon adsorption or incineration, that is demonstrated to achieve at least 81 percent overall VOC emissions reduction based on a performance averaging period.

In lieu of coating analyses as a means of establishing compliance when using reformulated coatings, the coating user may submit the following two data sheets as prima facie evidence of the actual VOC content of a coating: (a) coating as supplied data sheet, and (b) coating as applied data sheet. These data sheets are described in the EPA document Procedures for Certifying Quantity of Volatile Organic Compounds Emited by Paint, Ink, and Other Coatings, December 1984, EPA Publication No. 450/3-84-019.

For systems such as carbon adsorption, the achievable emissions reduction is based on demonstrating an average solvent recovery efficiency of 81 percent or better. Because some desorption cycles are not as efficient as others, as many as three desorption cycles could be required to acquire data representative of an average solvent recovery efficiency.

For systems such as incineration, the achievable emissions reduction is based on a reduction in VOC demonstrated in the most recent performance test. To account for variations in performance of control devices, the Technical Secretary should determine an appropriate performance averaging period on a case-by-case basis for each control device based on process variations, control device operations, and measurement variabilities.

In addition, RACT includes the use of good housekeeping and operational procedures to minimize VOC emissions from cleanup and coating/solvent storage, transfer, and mixing, including, but not limited to, the following:

- o Pumps should be visually inspected weekly for evidence of leaks. Any equipment leaks should be repaired as soon as practicable within 15 calendar days. A record, or log, of repairs should be maintained on the plant site by plant personnel. Information to be included in the log must include the following: a) the date the leak is observed and a description of the problem, b) dates of interim or attempted repair work and descriptions of the repair work, and c) the date the repair is completed and a description of the repair. A record that a weekly inspection has occurred should be maintained in a readily accessible location on the plant site with the equipment leak repair log.
- o Tight-fitting lids should be maintained on all containers of coatings and process and cleaning solvents. The shape of each lid should conform exactly to the shape of the container it covers and should fit tightly enough so that no free space is visually discernible around the seal of the container lid. Plant personnel should perform a daily inspection of all containers to ensure that all lids are correctly and securely in place. A record that such a daily inspection has occurred should be maintained on the plant site with the equipment leak repair log.

4.2 AIR POLLUTION IMPACTS

Implementing RACT will reduce VOC emissions from the coating line (including VOC emissions from storage and handling) by 81 percent or better from the uncontrolled level. This emission reduction is

based on conservative estimates that carbon adsorption or incineration systems have VOC control efficiencies of 90 percent and capture of 90 percent of VOC to the control device.[1] Actual performance of these systems may be much better. For example, incineration systems are demonstrated to achieve 98 percent efficiency in destroying VOC. This higher control device efficiency is used to calculate emission reductions presented in Chapter 5, Table 5-2. However, the emission reductions reported in Table 4-1 are based on a control device efficiency of 90 percent.

Table 4-1 presents VOC emissions and emission reductions associated with RACT for Model Plants A and B. The uncontrolled VOC emissions from paperboard coating for the model plants as presented in Table 2-1 are 34.8 megagrams per year (Mg/yr) (38.4 tons/yr) for Model Plant A and 580 Mg/yr (640 tons/yr) for Model Plant B. These uncontrolled emissions can be reduced by 81 percent using reformulated coatings (with reduced VOC content) or add-on control devices, such as incineration or carbon adsorption, to reduce VOC emissions primarily from the process oven. Therefore, VOC emissions from Model Plant A will be reduced by 28.2 Mg/yr (31.1 tons/yr) to a total controlled level of 6.6 Mg/yr (7.3 tons/yr). Similarly, Model Plant B emissions will be reduced by 470 Mg/yr (518 tons/yr) to a total controlled level of 110 Mg/yr (122 tons/yr).

4.3 WATER POLLUTION IMPACTS

RACT is not expected to have a significant impact on water pollution. Neither coating reformulation or incineration would be expected to have any impact on the amount or quality of wastewater generated in Shelby County.

Some increase in wastewater generation could occur with carbon adsorption control, although the increase is not expected to add significantly to the overall wastewater disposal volume of the plant. Steam desorption of the carbon bed would require about 190,000 liters (50,000 gallons) of water a year at Model Plant A and about 1.9 million liters (500,000 gallons) of water a year at Model Plant B.[2,3] Most of this would be recovered through air stripping or distillation (still bottoms) and would be disposed as wastewater. Water may be used to cool the VOC-laden oven exhaust stream, to generate steam for

TABLE 4-1. VOC EMISSIONS AND EMISSION REDUCTION FROM IMPLEMENTING RACT FOR MODEL PLANTS A AND B

	Model Plant A		Model Plant B	
Before RACT				
Uncontrolled VOC Emissions, Mg/yr (tons/yr)[a]	34.8	(38.4)	580	(640)
After RACT				
VOC Emission Reduction, Mg/yr (tons/yr)[b]	28.2	(31.1)	470	(518)
Controlled VOC Emissions, Mg/yr (tons/yr)[c]	6.6	(7.3)	110	(122)

[a]From Table 2-1.

[b]Based on overall VOC emisson reduction of 81 percent (assume 90% efficiency of control device and 90% of VOC routed to the control device) from the uncontrolled level using incineration, carbon adsorption, or reformulated coatings. Calculated by: (uncontrolled emissions) x 0.81. It is important to note that specific control techniques may achieve better emission reduction than RACT requirements specify.

[c]Calculated as the difference between uncontrolled VOC emissions and VOC emission reduction.

desorption, or to condense the steam-VOC exiting the desorbed carbon bed, but chiller or condensation water may already be present in the plant for other purposes. In this case, the additional water would not add to wastewater disposal, or may be recyclable, which would not generate wastewater. The VOC content of the discharged water would vary by local discharge allowances and solvent recovery processes.

4.4 SOLID WASTE IMPACTS

Coating reformulation and incineration would be expected to have a negligible impact on generation of solid waste.

Carbon adsorption control would result in some increased generation of solid waste. Maintenance of carbon bed efficiency requires periodic replacement or regeneration of the carbon, which generates some solid waste. Complete replacement of the carbon bed over a period of 1 year may require the annual disposal of 594 kg (1,310 lb) and 2,415 kg (5,325 lb) of carbon from Model Plants A and B, respectively.[2,3,4,5] The amount of carbon disposed, however, may be reduced by regenerating the carbon and replacing only the carbon that is lost during the carbon bed regeneration process (i.e., losses from thermal reactivation or screening operations). The carbon disposed from Model Plants A and B, assuming annual carbon regeneration, would be 215 kg (475 lb) and 875 kg (1,930 lb), respectively.[6]

Other solid waste generation could occur with carbon adsorption control, depending on the type of coating used or the extent of solvent recovery performed. If a coating is used that contains a vinyl copolymer or other lacquer or resinous substance that could polymerize or clog a carbon bed, a fabric filter might be necessary upstream of the adsorber to protect the carbon bed.[7] Coating solids, VOC, and other particulate matter collected by the filter would probably need to be disposed to a secured landfill or incinerated off-site; such a fabric filter at Model Plants A and B is estimated to collect about 15 Mg (17 tons) and 255 Mg (281 tons) of particulate matter, respectively.[11]

Although the type and volume of solid waste generation from solvent recovery depends on the system used, solid waste could include still bottom residue, or solid caustic soda, calcium chloride, or other dehydrating substance.[8,9]

4.5 ENERGY IMPACTS

Water-based reformulated coatings used on a paperboard coating line would not be anticipated to result in any significant increased energy impacts. High-solids reformulated coatings may require additional energy, however, because they are more viscous; additional energy may be needed to pump or atomize the slurry or to provide heat to lower the viscosity.

Incinerator control of VOC emissions is expected to increase energy requirements because of electrical and natural gas use. Model Plant A is anticipated to require 10 kWh of electricity and about 19 m^3 (662 ft^3) of natural gas every hour of operation. Model Plant B is anticipated to require 19 kWh of electricity and about 8.2 m^3 (289 ft^3) of natural gas every hour of operation.[11]

Carbon adsorption control of VOC emissions would require energy use to produce steam for carbon bed desorption, and to operate the adsorber (blow the steam through the bed and condense the resulting steam/VOC-laden airstream). Steam production and carbon bed operation would require 48 and 117 kWh per hour of operation for Model Plants A and B, respectively.[2-5] If distillation is used, Model Plants A and B would require an additional 30 and 150 kWh per hour of operation, respectively.[4,10]

4.6 REFERENCES

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5.0 CONTROL COST ANALYSIS OF RACT

The costs of implementing reasonably available control technology (RACT) for emissions of VOC from paperboard coating facilities are presented in this chapter. Costs of retrofitting process lines with a catalytic incinerator and carbon adsorption system are presented for the two model plants that are described in Chapter 2. Control costs are estimated from discussions with equipment vendors, paper coating facilities, solvent reclaimers, and information presented in EPA publications. The bases for these costs, including calculations, assumptions, model plant parameters, vendor estimates, etc., are presented in more detail in Appendix C. Costs presented in this chapter are based on February 1985 dollars. Engineering cost indexes are used where necessary to update costs to a common base year.

Section 5.1 presents the capital and annualized costs of installing catalytic incinerators to control VOC emissions from Model Plants A and B. Annualized costs for catalytic incineration are based on a factored method of estimation, which is generally accurate to $\pm$20 percent. Section 5.2 presents the capital and annualized costs and cost effectiveness of installing carbon adsorption systems at Model Plants A and B. Vendor estimates were used to calculate costs of carbon adsorption. These costs are estimated to be accurate within 10 to 20 percent. In addition, Section 5.2 discusses the assumptions used as the basis for the various control alternatives for recycling and disposal of solvents Cost effectiveness estimates are presented for both incineration and carbon adsorption control techniques in Sections 5.1.3 and 5.2.4.

The cost effectiveness estimates are useful to federal, State, and local air pollution control personnel as a means of evaluating and ranking a number of control technologies under consideration as RACT. Cost effectiveness is not used to determine the reasonableness of a given control technology. Factors other than cost effectiveness, such as the ability of a company to bear the cost of implementing a control strategy, and the attainment status of the area for the National Ambient Air Quality Standards (NAAQS), influence decisions on the economic feasibility of control options. For example, if the VOC emission reduction expected from the control technology under consideration is

needed to demonstrate attainment of the NAAQS, then a less cost-effective technology may be found to be reasonably available from an economic standpoint than might otherwise have been.

5.1 INCINERATION COSTS

The capital and annualized costs of catalytic incineration are presented in Tables 5-1 and 5-2, respectively, and are based on an estimation procedure presented in the EPA background information document for the proposed standards for the polymers and resins manufacturing industry.[1] Operating costs of catalytic incinerators are lower than those of thermal incinerators when the heat content of a waste gas stream is low, due to decreased supplemental fuel requirements. Catalytic incineration was determined to be less cost effective than carbon adsorption for Model Plant A; therefore, it is apparent that thermal incineration would be even less cost effective for control of Model Plant A than catalytic incineration (see Tables C-7 through C-13).

5.1.1 Capital Costs for Catalytic Incineration

The capital costs presented in Table 5-1 are based on an incineration system capable of 98 percent emission reduction for both model plants. The cost estimates shown in Table 5-1 are based on the operating parameters presented in detail in Appendix C, Section C.1. Total installed capital costs for catalytic incineration systems are about $319,000 for Model Plant A and about $447,000 for Model Plant B based on February 1985 dollars. These costs have been updated from June 1980 estimates using a "Fabricated Equipment" index of 1.155 = (336.5/291.3) to approximate February 1985 dollars.[4]

5.1.2 Annualized Costs for Catalytic Incineration

The annualized costs include direct cost items (such as operating labor, maintenance material and labor, catalyst requirement, and utilities) and indirect cost items (such as capital recovery, taxes, insurance, and administrative charges). The basis for the estimates given in Table 5-2 is presented in detail in Appendix C, Section C.1, and costs are calculated using a factored method of cost estimation. Table 5-2 shows that net annualized costs for Model Plants A and B are approximately $126,000 and $181,000, respectively. Annualized costs

TABLE 5-1. CAPITAL COSTS OF CATALYTIC INCINERATION SYSTEMS (February 1985 dollars)[a]

Cost Item	MODEL PLANT A	MODEL PLANT B
1. Incineration system, installed[b]	227,600	335,000
2. Piping and ducting from source to main incinerator duct, installed[b]	15,000	22,000
3. Ducts, fans, and stacks from main duct to incinerator and from incinerator to atmosphere, installed[b]	76,200	90,300
Total installed capital costs	318,800	447,300

[a]The basis for these costs is presented in detail in Appendix C, Section C.1.

[b]From capital costs presented in Appendix C, Tables C-3 and C-6 (given in June 1980 dollars), updated to February 1985 dollars; using cost index of

$$\frac{336.5}{291.3} = 1.155.^{4}$$

TABLE 5-2. ANNUALIZED COSTS FOR CATALYTIC INCINERATION SYSTEMS (February 1985 dollars)[a]

Cost Item	MODEL PLANT A	MODEL PLANT B
Direct Costs		
Operating Labor[b]	19,300	19,300
Maintenance Material and Labor[b]	15,900	22,400
Catalyst[b]	16,300	29,900
Utilities[b]		
Natural gas	8,560	12,500
Electricity	1,060	6,480
Indirect Costs		
Capital recovery[b]	51,900	72,800
Taxes, insurance and administrative charges[b]	12,800	17,900
Total annualized costs, $/yr	125,820	181,280
VOC emissions reduction,[c] Mg/yr (tons/yr)	30.6 (33.8)	510 (563)
Cost effectiveness, $/Mg ($/ton)	4,110 (3,720)	355 (322)

[a]The details of the costing procedure used in estimating annualized costs are given in Appendix C, Section C.1.

[b]From annualized costs presented in Appendix C, Tables C-3 and C-6 (given in June 1980 dollars), updated to February 1985 dollars, using a fabricated equipment cost index of $\frac{336.5}{291.3} = 1.155$.[4]

[c]VOC emission reduction is calculated as the product of the capture efficiency (90%) and the incineration efficiency (98%) for an overall reduction efficiency of 88 percent of uncontrolled emissions, presented in Table 4-1. Example calculation for Model Plant A: (0.88)(38.4 tons/yr) = 33.8 tons/yr VOC emission reduction.

have been updated from June 1980 dollars to February 1985 dollars using a Fabricated Equipment index of 1.155 (336.5/291.3).[4]

5.1.3 Cost Effectiveness

The annual VOC emission reduction for use of catalytic incineration and the cost effectiveness associated with this reduction are given in Table 5-2. For the purposes of calculating VOC emission reduction from catalytic incineration, a control efficiency of 98 percent for incinerators and a capture efficiency of 90 percent of VOC to the control device were assumed. As shown, the cost effectiveness for the model plants ranges from about $4,000/Mg for Model Plant A to about $400/Mg for Model Plant B.

5.2 CARBON ADSORPTION COSTS

Estimates of capital and annualized costs of carbon adsorption systems for control of paperboard coating lines at two model plants are based on average costs or best cost estimates from control equipment vendors and on EPA cost procedures.[5] All costs are based on February 1985 dollars. Model plant parameters are presented in Table 2-1. As explained in Section 5.1, there are differences in oven temperatures between Model Plants A and B to reflect differences in facility sizes and heating methods. Individual vendor estimates are presented in Appendix C, Section C.2.

5.2.1 Cost Assumptions

Both model plants are assumed to use a mixture containing coating material, toluene, and methyl ethyl ketone (MEK). Seventy percent by weight of the coating is assumed to be emitted as a VOC and collected by a fabric filter located upstream of the carbon adsorption system.[6] The coating is assumed to condense to a particulate before contacting the fabric filter; the fabric filter is assumed to be 99 percent efficient in collecting solids from the coating material. For purposes of this analysis, the coating material is assumed to have a total density of 0.94 kg/l (7.9 lb/gal).[6] Toluene, because of its low solubility in water, is expected to be decanted from the carbon adsorber and returned directly to the process.[8,9] Recycled toluene, therefore, results in a solvent recovery credit. MEK has a much higher solubility in water, however, and is assumed, therefore, to mix with the water used to desorb the carbon bed.

Capture efficiency of the VOC emissions, control efficiency of the carbon adsorber, and recovery efficiency of the distillation system are each assumed to be 90 percent. Toluene is recovered for reuse by decanting after the adsorber, and, therefore, is assumed to have an overall recovery efficiency of 81 percent. MEK recovery is reduced an additional 10 percent because of distillation, which results in a final recovery efficiency of 73 percent.

Four alternative methods for recovery and/or disposal of the MEK/water mixture were examined: (1) on-site MEK and water recovery using distillation, (2) off-site MEK and water recovery by an independent solvent recovery company, (3) off-site incineration, and (4) off-site landfilling. Table 5-3 provides a summary of estimated annualized costs for each of these alternative methods for both model plants; cost-effectiveness estimates for these methods are provided in Section 5.2.4, where possible.

On-site MEK and water recovery using distillation was determined to be the most economical of the recovery/disposal methods for several reasons. First, no recovery credit is available with solvent disposal. Second, all off-site disposal methods include a charge to the customer for transporting the mixture from the plant to the disposal site. Third, this MEK/water mixture is very dilute (2 to 3 percent MEK in water, based on vendor estimates of steam use per hour). Because the cost to dispose of the mixture is based on volume alone, the cost to dispose of a dilute mixture of solvent per gallon of solvent destroyed is unreasonable. In fact, no recovery services contacted would accept a solvent mixture containing less than 50 percent recoverable solvent.[13,14,15] Also, one incineration company requires a minimum of 10,000 Btu's per gallon in mixtures they handle; a 2 to 3 percent MEK mixture contains about 1600 Btu/gal.[19]

An on-site distillation system was estimated, therefore, to provide the most cost-effective means of separating and recovering the MEK and the water. The water can then be disposed to a publicly-owned treatment works, and the MEK can be reused. The carbon adsorber and the distillation system are each assumed to be 90 percent effective in recovering the solvents they receive.

TABLE 5-3. ANNUALIZED COSTS OF MEK/WATER RECOVERY OR DISPOSAL OPTIONS
(February 1985 dollars)

	Option	Model Plant A	Model Plant B
1.	On-site solvent recovery[a]	12,430	(5,500)[b]
2.	Off-site solvent recovery[c]	Not economical	Not economical
3.	Off-site incineration[d]	38,000	383,000
4.	Off-site landfill[e]	70,000	700,000

[a]References 10 and 11. Average estimated cost of distillation system. Includes MEK recovery credit assuming 73 percent overall MEK recovery and $0.79/kg ($0.36/lb) MEK cost[12]: A - $2,550; B - $42,570.

[b]( ) indicates cost savings.

[c]References 13, 14 and 15.

[d]References 16 and 17.
Includes transportation costs that assume bulk delivery in 5000-gallon truck.
A - $3,000/yr ($1.50/mile x 200 miles/round trip x 10 round trips/yr)
B - $30,000/yr ($1.50/mile x 200 miles/round trip x 100 round trips/yr)

[e]Reference 18.
Includes transportation costs that assume delivery in 55-gallon drums on trucks that can carry 40 drums per trip.
A - $8,700/yr ($3.78/loaded mile x 100 loaded miles/trip x 23 trips/yr)
B - $88,830/yr ($3.78/loaded mile x 100 loaded miles/trip x 235 trips/yr)

Several factors may change the costs presented in this chapter depending on the particular solvents and coatings used in any specific sheet-fed papercoating line. If an aziotrope forms during the distillation process, for example, a more expensive system may be required for separation of solvents. In addition, some of the coating materials used on some coating lines may not be trapped by a conventional fabric filter described in this analysis; in fact, a resinous coating may even condense in the adsorber. These resins could plug up the carbon and significantly decrease the carbon bed efficiency and life. In these cases, a more sophisticated fabric filter might be required upstream of the carbon adsorber to collect the coating material and protect the carbon bed. Because the coating material used in this cost analysis may cause this problem, Appendix C.3 presents an example of the cost increase that might be incurred by Model Plant A if such a fabric filter were installed. Also, if reformulated coatings and/or solvents could be used that contained little or no VOC's or no resinous coating material, the costs of fabric filtration, carbon adsorption, and distillation would be decreased or eliminated entirely.

5.2.2 Capital Costs

Table 5-4 presents the capital costs for purchase, installation, and operation of a carbon adsorption and distillation system for Model Plants A and B. Table 5-5 presents the capital costs for purchase, installation, and operation of a carbon adsorption system only. These costs assume the MEK/water mixture is disposed by incineration or landfilling. Three vendors of carbon adsorption systems, one vendor of solvent distillation systems, and one vendor selling both types of equipment were contacted to provide these cost estimates; the vendor-specific cost data are provided in Appendix C.2.[9,10,11,20,21] Average total installed capital costs for the carbon adsorption and distillation system are about $216,000 for Model Plant A and about $308,000 for Model Plant B. Total installed capital cost without the distillation system are about $176,000 for Model Plant A and about $253,000 for Model Plant B.

5.2.3 Annualized Costs

Annualized costs for carbon adsorption with distillation equipment for MEK recovery for both model plants are provided in Table 5-4.

TABLE 5-4. COSTS FOR CARBON ADSORPTION CONTROL WITH DISTILLATION EQUIPMENT FOR MEK RECOVERY
(February 1985 dollars)

Item	Model Plant A	Model Plant B
A. Capital Costs		
1. Purchase cost[a]	142,000	200,000
2. Total installed cost[a]	216,000	308,000
B. Annual Costs		
1. Steam[b]	3,070	30,500
2. Cooling water[c]	230	3,000
3. Electricity[d]	5,860	20,970
4. Carbon replacement[e]	2,515	20,448
5. Maintenance[f]	10,800	15,400
6. Operating labor[g]	2,360	7,850
7. Capital recovery[h]	29,380	41,890
8. Supervision of labor[i]	0	0
9. Taxes and administration[j]	8,640	12,320
10. Disposal cost[k]	0	0
TOTAL ANNUAL	62,860	152,380
C. Recovered product credit[l]	24,520	408,670
D. Net annual cost	38,340	256,290[m]
E. VOC emission reduction, Mg/yr (ton/yr)[n]	29.6 (32.7)	489 (539)
F. Cost effectiveness, $/Mg ($/ton)	1,300 (1180)	520[m] (480)[m]

[a]Average of four vendor cost estimates for an automated, 316-stainless steel constructed carbon adsorption unit, 90% efficiency, with fabric filter preceding unit, air stripper for water treatment, and decanter to separate toluene from MEK/water mixture.[9,11,20,21] These costs were compared with guidelines for estimating installed capital costs from Reference 5 and were determined reasonable. Distillation equipment cost estimated from two vendors.[10,11] Total installed costs include labor to install automated system.

[b]Steam requirements based on 235 lb/hr for Model Plant A and 700 lb/hr for Model Plant B from average of vendor estimates and cost of $7.26/1000 lb (Feb. 1985) for steam from Reference 5. A = (235 lb/hr)(1800 hr/yr)($7.26/1000 lb) = $3,070/yr. B = (700 lb/hr)(6000 hr/yr)($7.26/1000 lb) = $30,500/yr. Additional steam/electricity for distillation equipment would be 30 kWh for Model Plant A and 150 kWh for Model Plant B. Additional electricity would be:

TABLE 5-4. COSTS FOR CARBON ADSORPTION CONTROL WITH DISTILLATION EQUIPMENT FOR MEK RECOVERY
(February 1985 dollars)

FOOTNOTES (continued)

A = (30 kWh)($0.0622/kWh)(1800 h/yr) = $3,360
B = (150 kWh)($0.0622/kWh)(1800 h/yr) = $16,790.

[c]Based on 58 gal/min every 4 hours of operating time for Model Plant A and continuous operation for Model Plant B, and cost of $0.144 per 1000 gal for water based on cost from Reference 5.

$$A = (58 \text{ gal/min})(60 \text{ min/hr})\frac{(1800 \text{ hr})}{4}(\$0.144/1000 \text{ gal}) = \$230$$

$$B = (58 \text{ gal/min})(60 \text{ min/hr})(6000 \text{ hr})(\$0.144/1000 \text{ gal}) = \$3,000$$

[d]Based on 30 hp blower for steam for Model Plant A and a 50 hp blower for steam for Model Plant B; 0.746 kWh/hp, $0.0622/kWh.

$$\text{Model A} = (30 \text{ hp})\frac{(0.746 \text{ kWh})}{\text{hp}}\ \frac{(1800 \text{ h})}{\text{yr}}\frac{(\$0.0622)}{\text{kWh}} = \$2,500/\text{yr}$$

$$\text{Model B} = (50 \text{ hp})\frac{(0.746 \text{ kWh})}{\text{hp}}((1800/\text{yr})(\$0.0622) = \$4,180/\text{yr}$$

[e]Carbon replacement, on average, every year for Model Plant A and twice a year for Model Plant B. 1310 lb carbon and 5325 lb of carbon for Model A and B, respectively, and price per lb of carbon of $1.92:[22]

$$\text{Model A} = \frac{(1310 \text{ lb})(\$1.92/\text{lb})}{1} = \$2,515$$

$$\text{Model B} = \frac{(5325 \text{ lb})(\$1.92/\text{lb})}{0.5} = \$20,448$$

[f]0.05 x total installed capital cost.

[g]Assume 0 for carbon adsorbers since systems are automatic.[20,21] For distillation systems, however, added labor of 1 hour per shift is included.

$$\text{Model Plant A} = (1 \text{ man-hour/day})(\$7.27/\text{man-hour})(1.44)\frac{(1800 \text{ hr})}{8 \text{ hr/day}} = \$2,360/\text{yr}$$

$$\text{Model Plant B} = (3 \text{ man-hour/day})(\$7.27/\text{man-hour})(1.44)\frac{(6000 \text{ hr})}{24 \text{ hr/day}} = \$7,850/\text{yr}$$

[h]Capital recovery = 0.136 x total installed capital cost.

[i]Assume 0 since systems are automatic.

[j]0.04 x total installed capital cost.

TABLE 5-4. COSTS FOR CARBON ADSORPTION CONTROL WITH DISTILLATION EQUIPMENT FOR MEK RECOVERY
(February 1985 dollars)

FOOTNOTES (concluded)

[k]Disposal cost = no cost since toluene and MEK are recycled back to process and water is disposed to a publicly-owned treatment works (POTW). Assumes no additional POTW charge because incremental increase to plant for water disposal from adsorber would be negligible.

[l]Assumes that 81 percent of toluene introduced with the coating and recovered by the adsorber is recovered at a credit of $21,970 for Model Plant A and $366,100 for Model Plant B, and an additional credit for MEK recovered of $2,554 for A and $42,573 for B, based on 73 percent of introduced MEK recovered.[12]

Toluene recovered (Model A) = (0.81)(16.2 lb/h)(1800/hr)($0.93/lb) = $21,970
Toluene recovered (Model B) = (0.81)(81 lb/h)(6000/hr)($0.93/lb) = $366,100

MEK recovered (Model A) = (0.73)(5.4 lb/h)(1800 h/yr)($0.36/lb) = $2,554
MEK recovered (Model B) = (0.73)(27 lb/h)(6000 h/yr)($0.36/lb) = $42,573

[m]Cost savings.

[n]Assumes reduction of 90 percent of vinyl coating emissions (10 percent lost during capture). Assumes reduction of 81 percent of toluene emissions (90 percent capture x 90 percent control in adsorber). Assumes reduction of 73 percent of methyl ethyl ketone (MEK) emissions (90 percent capture x 90 percent control in adsorber x 90 percent recovery in distillation).

Annualized costs for carbon adsorption and disposal of the MEK/water mixture by incineration or landfilling are provided in Table 5-5. Annualized costs of operations such as utilities, labor, maintenance, capital recovery, and taxes and administration are based on vendor estimates and EPA cost procedures.[5] Carbon bed replacement is recommended once per year for Model Plant A and twice per year for Model Plant B based on conversations with equipment vendors.[11,22] Frequent replacement may be necessary because of the volume of coating material that escapes the fabric filter and accumulates in the bed over a year's time. Carbon bed regeneration can provide a viable option to carbon bed replacement; costs of the two options are comparable.

A carbon adsorption and solvent distillation system is estimated to have a net annualized cost of about $38,000 for Model Plant A and a net annual credit of about $260,000 for Model Plant B. Net annualized costs for a carbon adsorption system used in conjunction with incineration of the MEK/water mixture are about $64,000 and $120,000 for Model Plants A and B, respectively. Net annualized costs for a carbon adsorption system used in conjunction with landfilling of the MEK/water mixture are about $96,000 and $450,000 for Model Plants A and B, respectively.

5.2.4 Cost effectiveness

The cost effectiveness of implementing RACT represents the net annualized costs (or savings) per VOC emission reduction achieved. Tables 5-4 and 5-5 present the cost effectiveness of carbon adsorption control with three solvent recovery/disposal options. Model Plant A controlled by a carbon adsorber would have a cost effectiveness of $1,300/Mg ($1,180/ton) if the MEK were recovered on-site by distillation, $2,170/Mg ($1,970/ton) if the MEK/water mixture were incinerated, and $3,250/Mg ($2,940/ton) if the MEK/water mixture were landfilled. Model Plant B controlled by a carbon adsorber would have a cost effectiveness savings of $520/Mg ($480/ton) for MEK recovery by distillation, and costs of $250/Mg (220/ton) and $930/Mg (840/ton) for disposal of the MEK and water by incineration and landfilling, respectively.

TABLE 5-5. COSTS FOR CARBON ADSORPTION CONTROL WITH DISPOSAL OF MEK AND WATER BY INCINERATION OR LANDFILLING
(February 1985 dollars)

Item	Model Plant A	Model Plant B
A. Capital Costs		
1. Purchase cost[a]	110,000	155,000
2. Total installed cost	176,000	253,000
B. Annual Costs		
1. Steam[b]	3,070	30,500
2. Cooling water[c]	230	3,000
3. Electricity[d]	2,500	4,180
4. Carbon replacement[e]	2,515	20,448
5. Maintenance[f]	8,800	12,650
6. Operating labor[g]	0	0
7. Capital recovery[h]	23,940	34,410
8. Supervision of labor[i]	0	0
9. Taxes and administration[j]	7,040	10,120
10. Disposal cost[e]		
a. Incineration[k]	38,200	371,340
b. Landfilling[l]	69,950	705,030
TOTAL ANNUAL COST		
Incineration	86,300	486,650
Landfilling	118,050	820,340
C. Recovered product credit[m]	21,970	366,100
D. Net annual cost		
Incineration	64,330	120,548
Landfilling	96,080	454,240
E. VOC emission reduction, Mg/yr (ton/yr)	29.6 (32.7)	489 (539)
F. Cost effectiveness, $/Mg ($/ton)		
Incineration	2,170 (1,970)	250 (220)
Landfilling	3,250 (2,940)	930 (840)

TABLE 5-5. COSTS FOR CARBON ADSORPTION CONTROL WITH DISPOSAL OF MEK AND WATER BY INCINERATION OR LANDFILLING
(February 1985 dollars)

FOOTNOTES (continued)

[a]Average of four vendor cost estimates for 316 stainless steel constructed carbon adsorption unit, 90% efficiency, with fabric filter preceding unit, air stripper for water treatment, and decanter to separate toluene from MEK/water mixture.[9,11,20,21] These costs were compared with guidelines for estimating installed capital costs from Reference 5 and were determined reasonable.

[b]Steam requirements based on 235 lb/hr for Model Plant A and 700 lb/hr for Model Plant B from average of vendor estimates and cost of $7.26/1000 lb (Feb. 1985) for steam from Reference 5. A = (235 lb/hr)(1800 hr/yr) ($7.26/1000 lb) = $3,070/yr. B = (700 lb/hr)(6000 hr/yr)($7.26/1000 lb) = $30,500/yr.

[c]Based on 58 gal/min every 4 hours of operating time for A and continuous operation for B, and cost of $0.144 per 1000 gal for water based on costs from Reference 5.

$$\text{Model Plant A} = (58 \text{ gal/min})(60 \text{ min/hr})\left(\frac{1800 \text{ hr}}{4}\right)(\$0.144/1000 \text{ gal}) = \$230$$

$$\text{Model Plant B} = (58 \text{ gal/min})(60 \text{ min/hr})(6000 \text{ hr})(\$0.144/1000 \text{ gal}) = \$3,000$$

[d]Based on 30 hp blower for steam for Model Plant A and a 50 hp blower for steam for Model Plant B; 0.746 kWh/hp, $0.0622/kWh.

$$\text{Model Plant A} = (30 \text{ hp})\left(\frac{0.746 \text{ kWh}}{\text{hp}}\right)\left(\left(\frac{1800 \text{ h}}{\text{yr}}\right)\left(\frac{\$0.0622}{\text{kWh}}\right) = \$2,500/\text{yr}\right.$$

$$\text{Model Plant B} = (50 \text{ hp})\left(\frac{0.746 \text{ kWh}}{\text{hp}}\right)((1800/\text{yr})(\$0.0622) = \$4,180/\text{yr}$$

[e]Carbon replacement, on average, every year for Model Plant A and twice a year for Model Plant B. 1310 lb carbon and 5325 lb of carbon for Model Plants A and B, respectively, and price per lb of carbon of $1.92:[22]

$$\text{Model Plant A} = \frac{(1310 \text{ lb})(\$1.92/\text{lb})}{1} = \$2,515$$

$$\text{Model Plant B} = \frac{(5325 \text{ lb})(\$1.92/\text{lb})}{0.5} = \$20,448$$

[f]0.05 x total installed capital cost.

[g]Assume 0 for carbon adsorbers since systems are automatic.[20,21]

[h]Capital Recovery = 0.136 x total installed capital cost.

[i]Assume 0 since systems are automatic.

TABLE 5-5. COSTS FOR CARBON ABSORPTION CONTROL WITH DISPOSAL OF MEK AND WATER BY INCINERATION OR LANDFILLING
(February 1985 dollars)

FOOTNOTES (concluded)

[j]0.04 x total installed capital cost.

[k]Assume 2 to 3 percent MEK mixture, $0.73/gal incineration charge, $1.50/mile transportation charge, 200 miles per round trip, 10 trips per year for Model Plant A, and 100 trips per year for Model Plant B.[15,16,22]

[l]Assume 2 to 3 percent MEK mixture, landfill charge of $65/55-gallon drum, $3.78 per loaded mile, 100 loaded miles per trip, 23 trips per year for Model Plant A, and 235 trips per year for Model Plant B.[18,22]

[m]Assume that 81 percent of toluene introduced with the coating and recovered by the adsorber is recovered at a credit of $21,970 for Model Plant A and $366,100 for Model Plant B.[22]

Toluene recovered (Model A) = (0.81)(16.2 lb/h)(1800/hr)($0.93/lb) = $21,970
Toluene recovered (Model B) = (0.81)(81 lb/h)(6000/hr)($0.93/lb) = $366,100

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APPENDIX A

MODEL REGULATION

APPENDIX A. MODEL REGULATION

1200-3-18-____. Sheet-fed Paperboard Coating

(1) For the purpose of this rule, the following definitions apply:

(a) "Application area" means the area where the coating is applied by roll, rotogravure coater, or other coating applicator, including any tanks and/or apparatus containing feed material conveyed to the coating applicator.

(b) "Coating" means any water-based, organic solvent-based, or solvent-less extrusion type material that is applied directly to the paperboard.

(c) "Coating line" means the sheet-feeding area, application area, conveyer belt or roller, flashoff area(s), drying oven(s), and stacking area.

(d) "In VOC service" means that the equipment contains or contacts a process fluid that is at least 10 percent VOC by weight.

(e) "Sheet-fed paperboard coating" means the surface coating of paperboard sheets using water-based, organic solvent-based, or solvent-less extrusion type materials.

(f) "VOC destruction system" means an enclosed combustion device (such as a process heater, boiler, or incinerator) or a flare.

(g) "VOC recovery system" means a system capable of recovering VOC from exhaust gases through absorption, adsorption, or condensation.

(2) This rule will apply, in accordance with 1200-3-18- ____ -(3), to coating line(s) or other coating transfer, storage, or mixing operations that are associated with paperboard coating.

(3) Each owner or operator of a paperboard coating line shall:

(a) Demonstrate for each paperboard coating line an 81 percent overall VOC emission reduction or better as calculated over a performance averaging period; and

(b) Comply with good housekeeping and operational procedures to minimize VOC emissions by implementing the following measures:

1. Each pump in VOC service shall be checked by visual inspection each calendar week for indications of liquids dripping from the pump seal;
2. If any equipment in VOC service appears to be leaking on the basis of sight, smell, or sound, a readily visible identification tag shall be attached to the leaking equipment (until it is repaired) and the equipment repaired as soon as practicable within 15 days of detection. The identification tag shall indicate the date on which the leak was detected;
3. A log of repairs should be maintained in a readily accessible location on the plant site. Information to be included in the log must at least include the following: (a) the date the leak is observed and a description of the problem, (b) the date(s) of interim or attempted repair work and a description of the work performed, and (c) the date the repair is completed and a description of the repair;
4. Tight-fitting lids shall be maintained on all containers holding VOC materials. The shape of each lid shall conform exactly to the shape of the container it covers, and no free space shall be visually discernible around the seal of the lid;
5. Each container shall be checked by visual inspection once each calendar day to ensure that all lids are correctly and securely in place; and
6. A record that a weekly pump inspection and a daily container lid inspection have occurred will be maintained at the facility with the equipment leak repair log.

(4) Proof of compliance with the requirements of this rule shall be provided by:

(a) Methods approved by the Technical Secretary and consistent with:

1. EPA Guideline Series document, "Measurement of Volatile Organic Compounds," EPA-450/2-78-041,
2. Appendix A of "Control of Volatile Organic Emissions from Existing Stationary Sources - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles, and Light-Duty Trucks," EPA-450/2-77-008, and
3. Rules 1200-3-18-.43, .44, and .45.

(b) Demonstration of at least an 81 percent overall VOC emissions reduction shall be achieved by:

1. Use of coatings with reduced organic content as applied on each coating line such that VOC emissions are 19 percent or less of the average VOC emissions during the base period, which will be determined by the Technical Secretary. The testing period over which emissions are estimated when using reformulated coatings shall not exceed 24 hours; or
2. Use of a VOC recovery system and a demonstration of solvent recovery efficiencies of 81 percent or better for the performance averaging period as calculated by:

$$R = \frac{M_r}{\sum_{i=1}^{n} \left(W_{oi}\right)\left(M_{ci}\right)} \times 100$$

where:

"R" = the overall solvent recovery efficiency achieved for the performance averaging period.

"M_{ci}" = the total mass (kg) of each coating and solvent (i) applied during the period as determined from facility records.

"M_r" = the total mass (kg) of solvent recovered and otherwise accounted for the period.

"W_{oi}" = the weight fraction of VOC in each coating and solvent (i) applied during the period as determined from EPA Reference Methods or from the coating manufacturer's formulation data.

The performance averaging period shall be determined by the Technical Secretary by considering factors including the expected process variations, measurement variabilities, and control device operations; or

3. Use of a VOC destruction system and demonstration that the average emission reduction achieved over the averaging period is equal to or greater than the required reduction demonstrated in the most recent performance test. The performance averaging period shall be determined by the Technical Secretary by considering factors including the expected process variations, measurement variabilities, and control device operations.

(c) If approved by the Technical Secretary, the coating user may submit the following two data sheets as prima facie evidence of the actual VOC content of a coating in lieu of coating analyses: a) coating as supplied data sheet, and b) coating as applied data sheet. These data sheets are described and explained in the EPA document Procedures for Certifying Quantity of Volatile Organic Compounds Emitted by Paint, Ink, and Other Coatings, December 1984, EPA Publication No. 450/3-84-019, and

(d) Monitoring of process equipment and emission control equipment is required by the Technical Secretary to confirm continued compliance.

Authority: T.C.A. 54-3412. Administrative History. Original rule certified (effective date of rule).

APPENDIX B

ENFORCEMENT ASPECTS

B.0 ENFORCEMENT ASPECTS

Reasonably available control technology (RACT) for sheet-fe paperboard coating facilities specifies (1) an overall VOC emission reduction of 81 percent or better using reformulated coatings or add-on control devices, and (2) an inspection/maintenance program and good housekeeping and operational procedures designed to reduce emissions from leaking equipment and containers of VOC materials. Factors important to assessing compliance with RACT requirements are discussed in the following sections.

Section B.1 briefly discusses the factors for determining compliance with the RACT requirements for reformulated (low VOC) coatings. Section B.2 describes the test methods used to assess compliance with the requirements for add-on control devices. Section B.3 presents methods for determining compliance with the pump inspection and maintenance program and good housekeeping and operational procedures.

B.1 USE OF REFORMULATED COATINGS

RACT requirements specify that if substitute coatings are used, then VOC emissions should not exceed 19 percent of the average VOC emissions during the "base period." Thus, determination of compliance with the standard will consist of comparison of the reformulated coating (on an applied solids basis) with the composition of a representative base period coating (on an applied solids basis). The base period for a coating line is determined by the Technical Secretary, considering typical operating conditions on each affected coating line, the number of coatings used during the period, and the associated dilution solvent usage. The testing period over which emissions are estimated when using reformulated coatings shall not exceed 24 hours.

Comparison of the coatings on an applied solids basis requires information on the coating usage, volume of dilution solvent added to coatings, and coating composition. Coating and dilution solvent usage information can be obtained from plant purchase records. The composition of coatings may be determined by either of the following:
(1) Tennessee Rule 1200-3-18-.44 may be used to determine the VOC content of the coatings and EPA Test Method 24 for determination of

solids content. EPA Test Method 24 is used to determine the volume fraction solids of the coating(s) by calculation using the manufacturer's formulation; or (2) a certification by the manufacturer of the composition of coatings may be used (if supported by batch information records and approved by the Technical Secretary).

In lieu of coating analyses as a means of establishing compliance when using reformulated coatings, the coating user may submit the following two data sheets as prima facie evidence of the actual VOC content of a coating: (a) coating as supplied data sheet, and (b) coating as applied data sheet. These data sheets are described in the EPA document Procedures for Certifying Quantity of Volatile Organic Compounds Emitted by Paint, Ink, and other Coatings, December 1984, EPA Publication No. 450/3-84-019.

B.2 USE OF ADD-ON CONTROL DEVICES

The required level of VOC emission reduction may be achieved by add-on control devices, such as incineration or carbon adsorption systems. Tennessee Rule 1200-3-18-.45 specifies general test procedures for determining VOC control efficiency. Specific EPA test methods for measurement of VOC emissions are summarized in Table B-1. The complete test methods are presented in 40 CFR 60, Appendix A.

The performance averaging period shall be determined by the Technical Secretary by considering factors including the expected process variations, measurement variabilities, and control device operations.

Monitoring methods to confirm continued compliance with the control device requirements may include the following:

(1) For catalytic incineration systems, the temperature in the fire box may be monitored; and

(2) For carbon adsorption systems, either (a) a material balance may be performed over an appropriate period, or (b) the inlet and outlet concentration of the carbon adsorber may be determined.

B.3 INSPECTION/MAINTENANCE PROGRAM AND GOOD HOUSEKEEPING PROCEDURES

Determination of compliance with the inspection and maintenance program and good housekeeping and operational procedures can be determined only by visual inspection.

TABLE B-1. SUMMARY OF EPA TEST METHODS

Test Method Number	Title	Applicability and Principle
2	Determination of stack gas velocity and volumetric flow (Type S Pitot Tube)	This method is used to measure average gas velocity in a stack and for quantifying gas flow rate. This is determined from the gas density and measurement of the average velocity head with a Type S (Stausscheibe or reverse type) pitot tube. This method is not applicable at measurement sites other than ducts, stacks, or flues. It also cannot be used in cyclonic or swirling gas streams.
2A	Direct measurement of gas volume through pipes and small ducts	Measurement of gas flow through pipes and small ducts either in-line or exhaust positions temp. range of 0-50°C (32-125°F). Uses a gas volume meter with corrections made for local temperature and pressure conditions.
25	Determination of total gaseous nonmethane organic emissions as carbon	This method applies to the measurement of volatile organic compounds (VOC) as total gaseous nonmethane organics (TGNMO) as carbon in source emissions. An organic particulate filter may be needed as particulate will interfere with the test results. An emission sample is withdrawn from the stack of a constant rate through a chilled condensate trap by means of an evacuated sample tank. TGNMO is determined by combining the analytical results from independent analysis of the condensate trap and sample tank fractions.

TABLE B-1. SUMMARY OF EPA TEST METHODS (Concluded)

Test Method Number	Title	Applicability and Principle
25A	Determination of total gaseous organic concentration using a flame ionization analyzer	Applies to the measurement of total gaseous organic concentration of vapors consisting primarily of alkanes, alkenes, and/or aromatic hydrocarbons. The concentration is expressed either in terms of propane (or other appropriate gas) or in terms of carbon. A gas sample is extracted from the source through a heated process line, if necessary, and glass fiber filter to a flame ionization analyzer (FIA). Results are reported as volume concentration equivalents of the calibration gas or as carbon.
25B	Determination of total gaseous organic concentration using a nondispersive infrared analyzer	This method is used to measure the total gaseous organic concentration of alkane vapors. Other vapors may be measured using the general procedure in this method. The concentration is expressed either in terms of propane or carbon. A gas sample is extracted through a heated sample line, if necessary, and glass fiber filter to a nondispersive infrared analyzer. Reports are given in volume concentration equivalents of the calibration gas (or other appropriate gas) or in terms of carbon.

Compliance with the inspection and maintenance program by visual inspection is necessary to check equipment for indications of liquids dripping from pump seals and other equipment, and to ensure that container lids are securely placed. Plant owners and operators should maintain records of inspections in a readily accessible location and should make records available upon request. Records should include the date of detection of any equipment leak, the date for which an initial attempt at repair is made, the date upon which final repair is accomplished, and descriptions of all problems and repairs. Records should also be maintained that a weekly pump inspection and a daily container lid inspection have ocurred.

Compliance with requirements for good housekeeping and operational procedures is necessary to ensure proper use, storage, and disposal of VOC-containing materials. Enforcement personnel should visit each paperboard coating facility as deemed necessary to determine that containers of VOC materials are properly covered with tight-fitting lids and that openings are restricted to the extent feasible.

APPENDIX C - BASIS FOR THE COST ANALYSIS OF INCINERATION AND CARBON ADSORPTION SYSTEMS

APPENDIX C - BASIS FOR THE COST ANALYSIS OF INCINERATION AND CARBON ADSORPTION SYSTEMS

The purpose of this section is to present the basis for the costs of incineration and carbon adsorption systems for controlling oven exhaust VOC emissions from Model Plants A and B as described in Chapter 5. Included in this appendix are the parameters, assumptions, and calculations that were used to document the costs.

Section C.1 presents the basis for catalytic incineration costs presented in Section 5.2.1 and thermal incineration costs. Section C.2 presents the basis for carbon adsorption costs. Section C.2.1 includes vendor data used as the basis for the costs presented in Section 5.2.2. The cost of carbon adsorption is based on EPA and vendor costing information. Section C.2.2 presents an alternate approach to carbon adsorption costing that includes a High-Efficiency Air Filtration® system.

C.1 CATALYTIC AND THERMAL INCINERATION

Tables C-1 through C-3 present the basis for a cost estimate of a catalytic incinerator for Model Plant A. Table C-1 presents operating parameters and fuel requirements, Table C-2 presents stream parameters of Model Plant A, and Table C-3 presents the cost analysis for the model plant. The total annualized cost for catalytic incinerator control of Model Plant A is $108,890. Tables C-4, C-5, and C-6 show operating parameters and fuel requirements, stream parameters, and cost analysis, respectively, for Model Plant B. The total annualized cost for catalytic incinerator control of Model Plant B is $156,880.

Tables C-7 through C-13 present the calculations to estimate the lower heating value of Model Plants A and B for thermal incineration. Table C-7 presents the component lower heating values, which are subsequently used in Tables C-8 through C-10 for Model Plant A, and C-11 through C-13 for Model Plant B. The estimates indicate that Model Plant A and B would produce a heating value of 1,878 Btu/scf and 5.13 Btu/scf, respectively, neither of which is high enough to support combustion. Thermal incineration is, therefore, less cost effective than catalytic incineration due to a requirement of supplemental fuel.

Table C-1. OPERATING PARAMETERS AND FUEL REQUIREMENTS OF CATALYTIC INCINERATOR SYSTEMS, MODEL PLANT A

Item	Source of information or calculation	Value
Waste Gas Parameters		
(1) Flow rate (Q_2), scfm	From Table C-2	5230
(2) Amount of air present in the gas, scfm	0, if the waste gas contains VOC and nitrogen or other inert gas; and [(1 - volume percent VOC) ÷ (volume percent VOC)] x VOC volume flow (Q_1), scfm, if the waste gas contains VOC and air; 4870 x 528/492	5226
(3) Amount of air required for combustion at 20% excess, scfm	See footnote a.	
(4) Net amount of additional air required (Q_3), scfm	Item (3) - Item (2); and 0 if [Item (3) - Item (2)] is negative	0
(5) Total amount of gas to be treated (Q_4), scfm	Item (1) + Item (4)	5231
(6) Waste gas temperature at the inlet of PHR[b], °F	From Table C-2	170°F
(7) Waste gas temperature at preheater outlet or catalyst bed inlet, °F		600°F
(8) Temperature rise in the catalyst bed, °F	(25°F/1% LEL) x (%LEL from Table C-2)	70°F
(9) Flue gas temperature at catalyst bed outlet, °F	Item (7) + Item (8)	670
(10) Minimum possible temperature of flue gas at PHR outlet, °F	See footnote c.	
(11) PHR efficiency at maximum possible heat recovery[d], %	[Item (1) x (Item (7) - 25°F - Item (6))] ÷ [Item (5) x (Item (9) - Item (6))][e]	81%
(12) PHR design efficiency, %	See footnote f	65%

Table C-1. OPERATING PARAMETERS AND FUEL REQUIREMENTS OF CATALYTIC INCINERATOR SYSTEMS, MODEL PLANT A (concluded)

Item	Source of information or calculation	Value
(13) Waste gas temperature at PHR outlet °F	Item (12) [Item (9) - Item (6)] + Item (6)	495
(14) Amount of heat required by preheater at additional 10% for auxiliary, Btu/min	Item (5) x [Item (7) - Item (13)] x [Gas specific heat[g], Btu/scf, °F] x (110%)[h]	11,479
(15) Amount of heat required for preheater and auxiliary fuel, Btu/h	[Item (14) x 60 minutes/hour] x (10%)[h]	68,874
(16) Amount of natural gas required per year, 10^3 cfm	[Item (14) x (1,800 x 60) minutes/year] ÷ (1,040 Btu/cfm)	1192

[a]On volume basis (scfm/scfm): 11.45 for methane, 20.02 for ethane, 28.58 for propane, 54.31 for hexane, 17.15 for ethylene, and 45.73 for pentane. Values taken from p. 6-2 in Steam (Reference 1) for 100% total air and multiplied by 1.2 for 120% total air or 20% excess air.

[b]Primary heat recovery unit.

[c]Heat exchanger should be designed for at least 50°F above the gas dew point.

[d]The heat exchanger will be designed for 25°F lower than the preheater temperature so as to not cause changes in catalyst bed outlet temperature.

[e]Though the heat recovery to the temperature level of inlet gas is the maximum heat efficiency possible, in some cases this may not be possible due to gas dew point condition.

[f]Cost estimates are based on calculated maximum possible heat recovery up to an upper limit of 65 percent heat recovery.

[g]Gas specific heat varies with composition and temperature. Used 0.019 Btu/ft^3°F based on average specific heat of air for calculation purpose.

[h]Auxiliary fuel requirement is assumed to be 10 percent of total.

TABLE C-2. GAS PARAMETERS USED FOR ESTIMATING CAPITAL AND OPERATING COSTS OF CATALYTIC INCINERATORS, Model Plant A[a]

Item	Value
Stream conditions	
Temperature, °F	170
Pressure, psig	atm.
VOC content:	
Emission factor, kg/Mg of product	
Weight % of total gas (W_1)	
Mass flow rate, kg/h	(Emission factor, E, kg/Mg) x 1000 Mg/Gg (Plant production rate, P, Gg/yr) ÷ (8,600 h/yr)
lb/h	(kg/h) x (2.205 lb/kg); 42.6
Organic constituents, wt %	Vinyl lacquer, toluene, MEK
Average mol. wt. (M_1), lbs	
Volume flow (Q_1), scfm	(VOC mass rate, lb/h) ÷ (60 min/h) ÷ (Molecular weight (M_1), lbs/lb mole) x 385 scf/lb-mole at 68°) = 1.645 (EP/M_1) 3.23 (528/492) = 4
Heat content (H_1), Btu/scf	$(174.273)(2.521N_C + N_H)$[c]
Total gas:	
Constituents	VOC, air and others
Mass flow rate, lb/h	(VOC rate, lb/h) ÷ (wt% of VOC in gas, W_1/100%); 23,650
Molecular weight (M_2)	
Volume flow (Q_2), scfm	Gas mass rate, lb/h) ÷ (60 min/h) ÷ (Gas molecular weight (M_4), lb/lb mole) x (385 ft $/lb mole) = 1.645 (EP/$M_2W_1$); 4874 (528/492) = 5230
Air volume flow rate, scfm	(Total gas flow (Q_2), scfm) - (VOC volume flow (Q_1), scfm); 5230-4 = 5226
VOC concentration (A), % of LEL	(100) [(Volume flow of VOC, scfm) ÷ (Volume flow of air, scfm] ÷ LEL[d]; 3.3%
Heat content (H_2), Btu/total scf	See footnote e; 1878 (492/528) = 1.15

Footnotes for Table C-2

[a]Obtain gas parameters from Chapter 3, Reference 2, except those to be calculated.

[b]Calculate using weight percent values of VOC components.

[c]If the VOC heating value is not available, calculate it using heat of combustion values of 14,093 Btu/lb from carbon converted to CO_2 and 51,623 Btu/lb from hydrogen converted to water. N_C and N_H denote number carbon and hydrogen atoms in VOC.

[d]Lower explosion levels of ethylene, hexane, methanol, propane, butane, and pentane are 3.1, 1.32, 7.3, and 2.5, 1.9, and 1.4, respectively.

[e]Total gas heat content averages 50 Btu/scf at 100 percent LEL. Chapter 6, Reference 2.

Table C-3. CAPITAL AND OPERATING COST ESTIMATION FOR CATALYTIC INCINERATOR SYSTEMS, Model Plant A

Item	Value
Capital Costs	
Incineration system	
Installed cost, June 1980	From Reference 2, Figure E-6; $197,000
Piping & ducting (from sources to main incinerator duct)	5231 x $\frac{460 + 170}{528}$ = 6242 acfm; Duct 23.9"-36"
Installed cost	See Reference 2, Section E-7 for source flow rates, scfm; $10,071
Installed cost, June 1980[a]	Installed cost x 1.206 for piping Installed cost x 1.288 for ducting; $12,970
Ducts, fans & stacks (from main duct to incinerator and from incinerator to atmosphere)	
Installed cost[b]	From Reference 2, Figure E-5, for waste gas flow (Q_2), scfm; for 70% HR, 10 Btu/scf; $62,000
Installed cost, June 1980[c]	Installed cost x 1.064; $66,000
Total Installed Cost, June 1980	Sum of incineration systems, piping & ducting, and ducts, fans, & stacks; $276,000
Annualized Costs	
Direct costs	
Operating labor	$11,200 for systems with no heat recovery; and $16,700 for systems with heat recovery; $16,700
Maintenance material and labor	(0.05) x (Total installed capital cost, labor $ from Reference 2, Figure E-6); $13,800
Catalyst requirement	$2.7 x (Total gas volume flow(Q_4)[a] scfm, item 5 from Table C-1) = ($2.7 x Q_4); $14,120
Utilities:	
Fuel (natural gas)	($6.22/$10^3 ft^3$) x (Amount of natural gas required, $10^3 ft^3$, Item 16 of Table C-1)[e]; $7,410

Table C-3. CAPITAL AND OPERATING COST ESTIMATION FOR CATALYTIC INCINERATOR SYSTEMS (Concluded)

Item	Value
Electricity	($0.335/scfm x 1800/8600) x (Total gas volume flow rate (Q_4), scfm, Item 5 from Table C-1) for units with no heat recovery; and ($0.838/scfm x 1800/8600) x (Total gas volume flow rate (Q_4), scfm, Item 5 from Table C-1) for units with heat recovery; $920
Indirect Costs	
Capital recovery	(0.1627) x (Total installed capital cost, $ from Reference 2, Figure E-6); $44,900
Taxes, insurance and administrative charges	(0.04) x (Total installed capital cost, administrative charges $ from Reference 2, Figure E-6); $11,040
Total Annualized Costs[f]	Sum of total direct costs and total indirect costs; $108,890

[a]Updated using Chemical Engineering Plant Cost Index from December 1979 (247.6) to June 1980 (259.2).

[b]Piping updated using Chemical Engineering Plant Cost pipes, valves, and fittings index from August 1978 (273.1) to June 1980 (329.3). Ducting updated using Chemical Engineering Plant Cost fabricated equipment index from December 1977 (226.2) to June 1980 (291.3).

[c]See Reference 2, footnote c, Table E-7 for discussion on application of these costs developed by Enviroscience (Reference 3).

[d]Updated using Chemical Engineering Plant Cost fabricated equipment index from December 1979 (273.7) to June 1980 (291.3).

[e]Total gas flow including waste gas and additional combustion air.

[f]These costs are presented in June 1980 dollars but have been updated to February 1985 dollars in Chapter 5, Section 5.1.

Table C-4. OPERATING PARAMETERS AND FUEL REQUIREMENTS OF CATALYTIC INCINERATOR SYSTEMS, MODEL PLANT B

Item	Source of information or calculation	Value
Waste Gas Parameters		
(1) Flow rate (Q_2), scfm	From Table C-5	9600
(2) Amount of air present in the gas, scfm	0, if the waste gas contains VOC and nitrogen or other inert gas; and [(1 - volume percent VOC) ÷ (volume percent VOC)] x VOC volume flow (Q_1), scfm, if the waste gas contains VOC and air	8896
(3) Amount of air required for combustion at 20% excess, scfm	See footnote a.	
(4) Net amount of additional air required (Q_3), scfm	Item (3) - Item (2); and 0 if [Item (3) - Item (2)] is negative	0
(5) Total amount of gas to be treated (Q_4), scfm	Item (1) + Item (4)	9600
(6) Waste gas Temperature at the inlet of PHR[b], °F	From Table C-5	280°F
(7) Waste gas temperature at preheater outlet or catalyst bed inlet, °F		600°F
(8) Temperature rise in the catalyst bed, °F	(25°F/1% LEL) x (%LEL from Table C-5)	225-313
(9) Flue gas temperature at catalyst bed outlet, °F	Item (7) + Item (8)	825-913
(10) Minimum possible temperature of flue gas at PHR outlet, °F	See footnote c.	
(11) PHR efficiency at maximum possible heat recovery[d], %	[Item (1) x (Item (7) - 25°F - Item (6))] ÷ [Item (5) x (Item (9) - Item (6))][e]	54.1%
(12) PHR design efficiency, %	See footnote f	54.1%

Table C-4. OPERATING PARAMETERS AND FUEL REQUIREMENTS OF CATALYTIC INCINERATOR SYSTEMS, MODEL PLANT B (concluded)

Item	Source of information or calculation	Value
(13) Waste gas temperature at PHR outlet °F	Item (12) [Item (9) - Item (6)] + Item (6)	575
(14) Amount of heat required by preheater at additional 10% for auxiliary, Btu/min	Item (5) x [Item (7) - Item (13)] x [Gas specific heat[g], Btu/scf, °F] x (110%)[h]	5016
(15) Amount of heat required for preheater and auxiliary fuel, Btu/h	[Item (14) x 60 minutes/hour] x (10%)[h]	30,096
(16) Amount of natural gas required per year, 10^3 cfm	[Item (14) x (6,000 x 60) minutes/year] ÷ (1,040 Btu/cfm)	1736

[a]On volume basis (scfm/scfm): 11.45 for methane, 20.02 for ethane, 28.58 for propane, 54.31 for hexane, 17.15 for ethylene, and 45.73 for pentane. Values taken from p. 6-2 in Steam (Reference 1) for 100% total air and multiplied by 1.2 for 120% total air or 20% excess air.

[b]Primary heat recovery unit.

[c]Heat exchanger should be designed for at least 50°F above the gas dew point.

[d]The heat exchanger will be designed for 25°F lower than the preheater temperature so as to not cause changes in catalyst bed outlet temperature.

[e]Though the heat recovery to the temperature level of inlet gas is the maximum heat efficiency possible, in some cases this may not be possible due to gas dew point condition.

[f]Cost estimates are based on calculated maximum possible heat recovery up to an upper limit of 65 percent heat recovery.

[g]Gas specific heat varies with composition and temperature. Used 0.019 Btu/ft^3°F based on average specific heat of air for calculation purpose.

[h]Auxiliary fuel requirement is assumed to be 10 percent of total.

Table C-5. GAS PARAMETERS USED FOR ESTIMATING CAPITAL AND OPERATING COSTS OF CATALYTIC INCINERATORS, MODEL PLANT 8[a]

Item	Value
Stream conditions	
Temperature, °F	280
Pressure, psig	atm.
VOC content:	
Emission factor, kg/Mg of product	
Weight % of total gas (W_1)	(Emission factor, E, kg/Mg) x 1000 Mg/Gg (Plant production rate, P, Gg/yr) ÷ (8,600 h/yr)
Mass flow rate, kg/h	(kg/h) x (2.205 lb/kg); 213
lb/h	
Organic constituents, wt %	Vinyl lacquer, toluene, MEK
Average mol. wt. (M_1), lbs	(VOC mass rate, lb/h) ÷ (60 min/h) ÷ (Molecular weight (M_1), lbs/lb mole) x 385 scf/lb-mole at 68°) = 1.645 (EP/M_1)
Volume flow (Q_1), scfm	16.16 (528/492) = 17.34
Heat content (H_1), Btu/scf	$(174.273)(2.521N_C + N_H)^c$
Total gas:	
Constituents	VOC in air
Mass flow rate, lb/h	(VOC rate, lb/h) ÷ (wt% of VOC in gas, W_1/100%); 43,115
Molecular weight (M_2)	
Volume flow (Q_2), scfm	Gas mass rate, lb/h) ÷ (60 min/h) ÷ (Gas molecular weight (M_4), lb/lb mole) x (385 ft ^{3}/lb mole) = 1.645 (EP/M_2W_1); 9600
Air volume flow rate, scfm	(Total gas flow (Q_2), scfm) - (VOC volume flow (Q_1), scfm); 9583
VOC concentration (A), % of LEL	(100) [(Volume flow of VOC, scfm) ÷ (Volume flow of air, scfm] ÷ LEL[d]; 9.0
Heat content (H_2), Btu/total scf	See footnote e; 5.13

Footnotes for Table C-5

[a]Obtain gas parameters from Reference 2, Chapter 3, except those to be calculated.

[b]Calculate using weight percent values of VOC components.

[c]If the VOC heating value is not available, calculate it using heat of combustion values of 14,093 Btu/lb from carbon converted to CO_2 and 51,623 Btu/lb from hydrogen converted to water. N_C and N_H denote number carbon and hydrogen atoms in VOC.

[d]Lower explosion levels of ethylene, hexane, methanol, propane, butane, and pentane are 3.1, 1.32, 7.3, and 2.5, 1.9, and 1.4, respectively.

[e]Total gas heat content averages 50 Btu/scf at 100 percent LEL. Reference 2, Chapter 6.

Table C-6. CAPITAL AND OPERATING COST ESTIMATION FOR CATALYTIC INCINERATOR SYSTEMS, MODEL PLANT B

Item	Value
Capital Costs	
Incineration system	
Installed cost, June 1980	From Reference 2, Figure E-6; 290,000
Piping & ducting (from sources to main incinerator duct)	$9600 \times \frac{400 + 280}{530} = 13,404$ acfm; Duct 35"-36"
Installed cost	See Reference 2, Section E-7 for source flow rates, scfm. Cost = $14,768
Installed cost, June 1980[a]	Installed cost x 1.206 for piping Installed cost x 1.288 for ducting; $19,020
Ducts, fans & stacks (from main duct to incinerator and from incinerator to atmosphere)	
Installed cost[b]	From Reference 2, Figure E-5 for waste gas flow (Q_2), scfm; use 70% HR, 10 Btu/scf from Reference 3, Fig V-1b; $73,500
Installed cost, June 1980[c]	Installed cost x 1.064; $78,200
Total Installed Cost, June 1980	Sum of incineration systems, piping & ducting, and ducts, fans, & stacks; $387,220
Annualized Costs	
Direct costs	
Operating labor	$11,200 for systems with no heat recovery; and $16,700 for systems with heat recovery; $16,700
Maintenance material and labor	(0.05) x (Total installed capital cost, $ from Reference 2, Figure E-6); $19,360
Catalyst requirement	$2.7 x (Total gas volume flow(Q_4)[d] scfm, item 5 from Table C-4) = ($2.7 x Q_4); $25,920
Utilities:	
Fuel (natural gas)	($6.22/$10^3 ft^3$) x (Amount of natural gas required, $10^3 ft^3$, Item 16 of Table C-4)[e]; $10,800

Table C-6. CAPITAL AND OPERATING COST ESTIMATION FOR CATALYTIC INCINERATOR SYSTEMS, MODEL PLANT B (Concluded)

Item	Value
Electricity	($0.335/scfm x 6000/8600) x (Total gas volume flow rate (Q_4), scfm, Item 5 from Table C-4) for units with no heat recovery; and ($0.838/scfm x 6000/8600) x (Total gas volume flow rate (Q_4), scfm, Item 5 from Table C-4) for units with heat recovery; $5610
Indirect Costs	
Capital recovery	(0.1627) x (Total installed capital cost, $ from Reference 2, Figure E-6); $63,000
Taxes, insurance and administrative charges	(0.04) x (Total installed capital cost, administrative charges $ from Reference 2, Figure E-6); $15,490
Total Annualized Costs[f]	Sum of total direct costs and total indirect costs; $156,880

[a]Updated using Chemical Engineering Plant Cost Index from December 1979 (247.6) to June 1980 (259.2).

[b]Piping updated using Chemical Engineering Plant Cost pipes, valves, and fittings index from August 1978 (273.1) to June 1980 (329.3). Ducting updated using Chemical Engineering Plant Cost fabricated equipment index from December 1977 (226.2) to June 1980 (291.3).

[c]See Reference 2, footnote c, Table E-7 for discussion on application of these costs developed by Enviroscience (Reference 3).

[d]Updated using Chemical Engineering Plant Cost fabricated equipment index from December 1979 (273.7) to June 1980 (291.3).

[e]Total gas flow including waste gas and additional combustion air.

[f]These costs are presented in June 1980 dollars but have been updated to February 1985 dollars in Chapter 5, Section 5.1.

TABLE C-7. COMPONENT LOWER HEATING VALUES

a) Vinyl chloride (Ethene, Chloro-) CH_2:CHCl 62.5 MW

$$LHV \sim [19.8 + 2(94.052) + 3/2\ (57.7979) - 24.7]\ \frac{1 kcal}{gmol} \times \frac{3.968\ \frac{Btu}{kcal} \times 453.6\ \frac{gmol}{lb\ mol}}{62.5\ \frac{lb}{lb\text{-}mol}} = \underline{7770\ Btu/lb}$$

b) Vinyl acetate (Acetic acid, ethenyl ester) $CH_3CO_2CHCH_2$ 86.09 MW
ΔH_f = -70.10 kcal/mol $C_4H_6O_2$

$$LHV \sim [-70.10 + 4(94.052) + 6/2\ (57.7979)] \times \frac{3.968 \times 453.6}{86.09}$$

= 10,020 Btu/lb

1) Vinyl Lacquer: $\frac{7770 + 10,020}{2}$ = 8900 Btu/lb

2) Toluene (Methyl benzene, Phenyl methane) 92.15 MW

LHV = 17,601 Btu/lb

3) Ketone, ethyl methyl, 2-Butanone $CH_3CH_2COCH_3$ 72.12 MW

$$LHV \sim [-75.8(94.052) + 8/2(57.7979)] \times \frac{3.968 \times 453.6}{72.12} = \underline{13,720\ Btu/lb}$$

TABLE C-8. VOLUME FLOW OF EXHAUST GAS, MODEL PLANT A

VOC Emissions:

1) Vinyl Lacquer: $0.7 \frac{\text{lb VOC}}{\text{lb coating}} \times 7.9 \frac{\text{lb}}{\text{gal coating}} \times 3.8 \frac{\text{gal}}{\text{hr}} = 21.0 \text{ lb/hr}$

2) Toluene: $1 \frac{\text{lb VOC}}{\text{lb solvent}} \times 7.2 \frac{\text{lb}}{\text{gal solvent}} \times 2.25 \frac{\text{gal}}{\text{hr}} = 16.2 \text{ lb/hr}$

3) MEK: $1 \frac{\text{lb VOC}}{\text{lb solvent}} \times 6.4 \frac{\text{lb}}{\text{gal}} \times 0.84 \frac{\text{gal}}{\text{hr}} = 5.4 \text{ lb/hr}$

$21.0 + 16.2 + 5.4 = 42.6$ lb/hr.

Volumetric Flow of Organics

$$= \frac{359 \text{ scf/lb-mol}}{60 \text{ min/hr}} \left(\frac{21.0 \text{ lb/hr}}{72.42 \text{ lb/lb-mol}} + \frac{16.2}{92.5} + \frac{5.4}{72.12} \right)$$

$= 3.23$ scfm at 32°F

Volumetric Air Flow = 5250 at 70°F $\left(\frac{460 + 32}{460 + 70} \right)$ - 3.23

= 4870 scfm at 32°F

Mass Air Flow = $4870 \text{ scfm} \times \frac{60 \text{ min/hr}}{359 \text{ scf/lb-mol}} \times 29 \frac{\text{lb}}{\text{lb-mol}}$

= 23,610 lb/hr

TABLE C-9. WASTE GAS CHARACTERISTICS, MODEL PLANT A

Composition Mix		Molecular Wt.
99.81 air	0.79 N_2, 0.21 O_2	29.0
0.089 vinyl lacquer	0.5 C_2H_2Cl, 0.5 $C_4H_6O_2$	72.42
0.069 toluene	C_7H_8	92.15
0.023 MEK	C_4H_8O	72.12

lb-mols	Lower Heating Value
99.81/29.0 = 3.44	0
0.089/72.42 = 0.00123	8900
0.069/92.15 = 0.00075	17,601
0.023/72.12 = 0.00032	13,720

Assume chlorine negligible on oxygen requirements and corrosiveness.

Btu/lb w.g.

.00089 x 8900 = 7.921
.00069 x 17,601 = 12.145
.00023 x 13,720 = 3.156
23.222 Btu/lb w.g.

TABLE C-10. LOWER HEATING VALUE, MODEL PLANT A

$$23.222 \frac{\text{Btu}}{\text{lb w.g.}} \times 29.03 \frac{\text{lb}}{\text{lb-mol}} = 675.5 \frac{\text{Btu}}{\text{lb-mol}}$$

$$\frac{675.5 \frac{\text{Btu}}{\text{lb-mol}}}{359 \frac{\text{scf}}{\text{lb-mol}}} = 1.878 \frac{\text{Btu}}{\text{scf @ 32°F*}}$$

*This heating value is too low to support combustion. Thus, a thermal incinerator is not cost effective.

TABLE C-11. VOLUME FLOW OF EXHAUST GAS, MODEL PLANT B

VOC Emissions: Model Plant B has 5 times the emissions of Model Plant A on an hour basis.

1) Vinyl Lacquer: 21.0 lb/hr x 5 = 105 lb/hr
2) Toluene: 16.2 lb/hr x 5 = 81 lb/hr
3) MEK: 5.4 lb/hrx 5 = 27 bl/hr
213 lb/hr

Volumetric Flow Rate

$$= \frac{359 \text{ scf/lb-mol}}{60 \text{ min/hr}} \left(\frac{105 \text{ lb/hr}}{72.42 \text{ lb/lb-mol}} + \frac{81}{92.5} + \frac{27}{72.12} \right)$$

= 16.16 scfm at 32°F

Volumetric Air Flow = 9600 scfm at 70°F $\left(\frac{460 + 32}{460 + 70}\right)$ - 16.16 scfm at 32°F

= 8896 scfm at 32°F

Mass Air Flow = 8896 scfm x 60/359 x 29.0 = 43,115 lb/hr

Total Gas Flow: 43,115 + 213 = 43,328 lb/hr

TABLE C-12. WASTE GAS CHARACTERISTICS, MODEL PLANT B

Composition Mix		Molecular Wt.
99.51 air	0.79 N_2, 0.21 O_2	29.0
0.24 vinyl lacquer	0.5 C_2H_2Cl, 0.5 $C_4H_6O_2$	72.42
0.19 toluene	C_7H_8	92.15
0.062 MEK	C_4H_8O	72.12

lb-mols		Lower Heating Value (LHV)
99.51/29.0	= 3.431	0
0.24/72.42	= 0.0033	8900
0.19/92.15	= 0.0021	17,601
0.062/72.12	= 0.0009	13,720

Assume chlorine negligible on oxygen requirements and corrosiveness.

Btu/lb w.g.

.0024 x 8900 = 21.36
.0019 x 17,601 = 33.44
.00062 x 13,720 = 8.51
63.31 Btu/lb w.g.

TABLE C-13. LOWER HEATING VALUE, MODEL PLANT B

$$63.31 \frac{\text{Btu}}{\text{lb w.g.}} \times 29.09 \frac{\text{lb.}}{\text{lb-mol}} = 1841 \frac{\text{Btu}}{\text{lb-mol}}$$

$$\frac{1841 \frac{\text{Btu}}{\text{lb-mol}}}{359 \frac{\text{scf}}{\text{lb-mol}}} = 5.13 \frac{\text{Btu}}{\text{scf}}^{*}$$

*This heating value is too low to support combustion. Thus, a thermal incinerator is not cost effective.

C.2 CARBON ADSORPTION

C.2.1 Vendor Data

Capital and annualized costs of carbon adsorption control of sheet-fed paperboard coating lines were calculated based on estimates from three vendors of carbon adsorption equipment, one vendor of solvent distillation equipment, and one vendor of both types of equipment. Tables C-14 through C-17 summarize the data obtained from each carbon adsorption vendor; Table C-18 summarizes data provided by the vendor of distillation equipment. Total annualized cost estimates ranged from $40,000 to $57,000 for Model Plant A and from $83,000 to $130,000 for Model Plant B for adsorption only. The one cost estimate for both adsorption and distillation was $63,000/yr for Model Plant A and $139,500/yr for Model Plant B. Total annualized costs for distillation alone were estimated to be $17,000 and $40,000 for Model Plants A and B, respectively.

C.2.2 Carbon Adsorption with High-Efficiency Air Filtration®

The four vendor cost estimates provided in Tables C-14 through C-17 include a cost for a conventional rollometric fabric filter that is designed to remove paper dust and particles and designed to operate at a pressure drop of about 0.0105 kpa (2 in. w.c.).[9] When a paperboard coating line uses a resinous coating material (e.g., a copolymer of vinyl chloride and vinyl acetate), this conventional fabric filter may not trap the coating material because of the small particle size of the resin and because of the low pressure drop across the filter. The coating material could then enter and plug up the carbon bed, significantly decreasing the efficiency of the system and bed life. In these instances, a more sophisticated fabric filtration system, such as a High Efficiency Air Filtration (HEAF®) system, may be necessary upstream of the adsorber to collect the coating material and protect the carbon bed. A HEAF® is a rollometric type filter that has a small mesh and uses a high power fan to increase the pressure drop across the fabric filter. Both features permit it to collect smaller particles. Any filter that is used to collect particles of a resinous coating material cannot be cleaned from a filter by shaking, rapping, or by water and, therefore, must be disposable. Table C-19 presents the costs of carbon

adsorption including the costs of a HEAF® system installed on Model Plant A.

Table C-14. VENDOR COST ESTIMATE NO. 1 - CARBON ADSORPTION[a]
(February 1985 dollars)

Cost Item	Model Plant A	Model Plant B
A. Capital Cost		
1. Purchase cost[b]	115,000	150,000
2. Total installed cost[c]	160,000	205,000
B. Annual Costs		
1. Steam[d]	820	21,780
2. Cooling water[e]	470	2,330
3. Electricity[f]	2,090	11,140
4. Carbon replacement[g]	600	1,200
5. Maintenance	8,000	10,250
6. Operating labor	0	0
7. Capital recovery	21,760	27,880
8. Supervision of labor	0	0
9. Taxes and administration	6,400	8,200
TOTAL ANNUAL COST[h]	40,140	82,780

[a]Reference 4.

[b]Purchase cost includes a 316-stainless steel carbon adsorber with air stripper and condenser.

[c]Total installed cost = purchase cost plus piping, installation, etc.

[d]Estimated 2000 lb of steam per day, for Model Plant A and 4000 lb per day for Model Plant B.

[e]Estimated 30 gallons per minute (continuous), or about 2000 to 3000 gal/day for Model Plant A; Model Plant B consumption rate estimated to be 30 to 50 percent higher.

A = (30 gal/min)(60 min/hr)(1800 hr/yr)($0.144/1000 gal) = $470
B = (45 gal/min)(60 min/hr)(6000 hr/yr)($0.144/1000 gal) = $2,330

[f]Estimated to use an air operated blower for steam that is run continuously and has 25 hp; Model B estimated to require a 35-40 hp blower.

Model A = (25 hp)(0.746 kWh/hp)(1800 hr/yr)($0.0622/kWh) = $2,090/yr
Model B = (40 hp)(0.746 kWh/hp)(6000 hr/yr)($0.0622/kWh) = $11,140/yr

[g]Estimated 2000 lb of carbon per year at $3 per pound for Model A and 4000 lb of carbon per year at $3 per pound for Model B; replace carbon every 10 years.

$$A = \frac{(2000 \text{ lb carbon/yr})(\$3/\text{lb carbon})}{10 \text{ yrs}} = \$600/\text{yr}$$

$$A = \frac{(4000 \text{ lb carbon/yr})(\$3/\text{lb carbon})}{10 \text{ yrs}} = \$1200/\text{yr}$$

[h]Total annual costs do not include costs to recover or dispose of solvent mixtures exiting the adsorber.

Table C-15. VENDOR COST ESTIMATE NO. 2 - CARBON ADSORPTION[a]
(February 1985 dollars)

Cost Item	Model Plant A	Model Plant B
A. Capital Cost[c]		
1. Purchase cost[b]	90,400	156,200
2. Total installed cost[c]	165,400	256,200
B. Annual Costs[c]		
1. Steam	2,860	38,100
2. Cooling water	230	3,000
3. Electricity	2,590	13,920
4. Carbon replacement	200	810
5. Maintenance	8,250	12,810
6. Operating labor	0	0
7. Capital recovery	22,494	34,843
8. Supervision of labor	0	0
9. Taxes and administration	6,616	10,248
TOTAL ANNUAL COST[d]	43,150	113,730

[a]Reference 5.

[b]Includes an air stripper.

[c]Assumed same costs as reported in Reference 7.

[d]Total annual costs do not include costs to recover or dispose of solvent mixtures exiting the adsorber.

Table C-16. VENDOR COST ESTIMATE NO. 3 - CARBON ADSORPTION AND DISTILLATION[a]
(February 1985 dollars)

Cost Item	Model Plant A		Model Plant B	
	Adsorption and Distillation	Adsorption Only	Adsorption and Distillation	Adsorption Only
A. Capital Cost				
1. Purchase cost	--	--	--	--
2. Total installed cost	230,000	200,000	350,000	300,000
B. Annual Costs				
1. Steam	2,250	2,250	30,000	30,000
2. Cooling water	300	300	1,000	1,000
3. Electricity[b]	7,650	7,650	25,500	25,500
4. Carbon replacement[c]	1,510	1,510	6,130	6,130
5. Maintenance	11,500	10,000	17,500	15,000
6. Operating labor	0	0	0	0
7. Capital recovery	31,280	27,200	47,600	40,800
8. Supervision of labor	0	0	0	0
9. Taxes and administration	9,300	8,000	14,000	12,000
TOTAL ANNUAL COST[d]	63,140	56,910	139,500	130,430

[a]Reference 6.

[b]Electricity cost estimated at $4.25 per operating hour.

[c]Carbon replacement:

Model Plant A = Replace carbon every year for vinyl coating; replace carbon every 5 years for toluene and MEK. Assume 1/2 carbon for vinyl coating and 1/2 for solvent. Assume carbon costs $1.92/lb.

$$\text{Vinyl coating} = \frac{1/2\ (1310\ \text{lb C})(\$1.92/\text{lb C})}{1\ \text{yr}} = \$1{,}258$$

$$\text{Solvent} = \frac{1/2\ (1310)(\$1.92/\text{lb C})}{5} = \$\ 252$$

Total Model Plant A Carbon replacement Cost = $1,510

Model Plant B =

$$\text{Vinyl coating} = \frac{1/2\ (5325\ \text{lb C})(\$1.92/\text{lb C})}{1} = \$5{,}112$$

$$\text{Solvent} = \frac{1/2\ (5325)(\$1.92/\text{lb C})}{5} = \$1{,}002$$

Total Model Plant B Carbon replacement Cost = $6,130

[d]Total annual costs do not include credits from recovering solvents using adsorption with distillation or using adsorption only. Adsorption with distillation would result in lower net annual cost than adsorption only because additional credit would result from recovery of MEK.

Table C-17. VENDOR COST ESTIMATE NO. 4 - CARBON ADSORPTION[a]
(February 1985 dollars)

Cost Item	Model Plant A	Model Plant B
A. Capital Cost		
1. Purchase cost	105,000	150,000
2. Total installed cost	180,000	250,000
B. Annual Costs		
1. Steam	2,860	38,100
2. Cooling water	230	3,000
3. Electricity	2,500	13,920
4. Carbon replacement	200	810
5. Maintenance	9,000	12,500
6. Operating labor[b]	0	0
7. Capital recovery	24,500	34,000
8. Supervision of labor	0	0
9. Taxes and administration	7,200	10,000
TOTAL ANNUAL COST[c]	46,490	112,330

[a]Reference 7.

[b]No operating labor required because system is automatic.

[c]Total annual costs do not include costs to recover or dispose of solvent mixtures exiting the adsorber.

Table C-18. VENDOR COST ESTIMATE NO. 5 - DISTILLATION[a]
(February 1985 dollars)

Cost Item	Model Plant A	Model Plant B
A. Capital Cost		
1. Purchase cost	40,000	55,000
2. Total installed cost[b]	48,000	66,000
B. Annual Costs		
1. Steam[c]	0	0
2. Cooling water[c]	0	0
3. Electricity, kWh	3,360	16,790
4. Maintenance	2,400	3,306
5. Operating labor[d]	2,360	7,850
6. Capital recovery	6,528	8,976
7. Supervision of labor	0	0
8. Taxes and administration	1,920	2,640
TOTAL ANNUAL COST[e]	16,570	39,560

[a]Reference 8.

[b]Cost for distillation system to separate a mixture of 2 percent MEK in water.

[c]No more than that already required for the adsorber.

[d]Assumes one hour labor per shift.

[e]Total annual costs do not include credits from MEK recovery for Model Plants A or B.

Table C-19. COSTS FOR CARBON ADSORPTION CONTROL OF MODEL PLANT A WITH DISTILLATION EQUIPMENT FOR MEK RECOVERY AND WITH A HIGH-EFFICIENCY AIR FILTRATION SYSTEM® (February 1985 Dollars)

Cost	Adsorption and Distillation		HEAF®
A. Capital Costs			
1. Purchase	142,000[a]		45,000[b]
2. Total installed	216,000		49,500[c]
B. Annualized Costs			
1. Steam[d]	3,070		0
2. Cooling water[e]	230		0
3. Electricity[f]	5,860		5,000
4. Carbon replacement[g]	2,515		--
5. HEAF® filter bag replacement[h]	--		2,455
6. Maintenance[i]	10,800		2,480
7. Operating labor[j]	2,360		2,360
8. Capital recovery[k]	29,380		6,730
9. Supervision of labor[l]	0		0
10. Taxes and administration[m]	8,640		1,980
11. Disposal cost[n]	0		6,000
Total annualized cost	62,860		27,010
Total annualized cost for Model Plant A		89,870	
C. Recovered product credit[o]		24,520	
D. Net annualized cost		65,350	
E. VOC emission reduction, Mg/yr (ton/yr)[p]		29.6 (32.7)	
F. Cost Effectiveness, $/Mg ($/ton)		2,200 (2,000)	

[a]Average of four vendor cost estimates for automated 316-stainless steel constructed carbon adsorption unit, 90% efficiency, with fabric filter preceeding unit, air stripper for water treatment, and decanter to separate toluene from MEK/water mixture.[4,5,6,7] Distillation equipment cost estimated from two vendors[6,8]

[b]Reference 9.

[c]Assumed 10 percent of HEAF® cost.

Table C-19. COSTS FOR CARBON ADSORPTION CONTROL OF MODEL PLANT A WITH DISTILLATION EQUIPMENT FOR MEK RECOVERY AND WITH A HIGH-EFFICIENCY AIR FILTRATION SYSTEM® (February 1985 Dollars)

FOOTNOTES (continued)

[d]Steam requirements based on 235 lb/hr for Model Plant A from average of vendor estimates and cost of $7.26/1000 lb (Feb. 1985) for steam. A = (235 lb/hr)(1800 hr/yr) ($7.26/1000 lb) = $3,070/yr. Additional steam/electricity for distillation equipment would be 30 kWh for Model Plant A. Distillation cost added under electricity.

[e]Based on 58 gal/min every 4 hours of operating time for Model Plant A, and cost of $0.144 per 1000 gal for water.

$$A = (58 \text{ gal/min})(60 \text{ min/hr})\left(\frac{1800 \text{ hr}}{4}\right)(\$0.144/1000 \text{ gal}) = \$230$$

[f]Based on 30 hp blower for steam, 30 kWh for distillation, and a 60-hp fan for HEAF® for Model Plant A; 0.746 kWh/hp, $0.0622/kWh.

$$\text{Steam} = (30 \text{ hp})\left(\frac{0.746 \text{ kWh}}{\text{hp}}\right)\left(\frac{1800 \text{ h}}{\text{yr}}\right)\left(\frac{\$0.0622}{\text{kWh}}\right) = \$2,500/\text{yr}$$

Distillation = (30 kWh)(0.0622/kWh)(1800 h/yr) = $3,360/yr

HEAF® Fan = (60 hp)(0.746 kWh/hp)(1800 h/yr)($0.0622/kWh) = $5,000/yr

[g]Carbon replacement, on average, 1310 lb carbon every year for Model Plant A; price per lb of carbon of $1.92:

$$\text{Model A} = \frac{(1310 \text{ lb})(\$1.92/\text{lb})}{1 \text{ yr}} = \$2,515$$

[h]Assume annual filter bag cost is 10 percent of HEAF® annual costs.

[i]0.05 x total installed capital cost.

[j]Assume 0 for carbon adsorbers since systems are automatic.[4,7] One hour per shift is included. Assume 1 hour per shift for distillation system and 1 hour per shift for HEAF®.

$$\text{Model Plant A} = (1 \text{ man-hour/day})(\$7.27/\text{man-hour})(1.44)\left(\frac{1800 \text{ hr}}{8 \text{ hr/day}}\right) = \$2,360/\text{yr}$$

[k]Capital recovery = 0.136 x total installed capital cost.

[l]Assume 0 since systems are essentially automatic.

[m]0.04 x total installed capital cost.

Table C-19. COSTS FOR CARBON ADSORPTION CONTROL OF MODEL PLANT A WITH DISTILLATION EQUIPMENT FOR MEK RECOVERY AND WITH A HIGH-EFFICIENCY AIR FILTRATION SYSTEM[a]
(February 1985 Dollars)

FOOTNOTES (concluded)

[n]Solvent disposal cost = 0 because toluene and MEK are recycled back to process and water is disposed to POTW. Assumes no additional POTW charge because incremental increase to plant for water disposal from adsorber would be negligible. Fabric filter disposal cost assumes filter adds 10 percent to total weight, and that disposal is performed by incineration 200 miles away, 10 times a year at $0.08/lb + $1.50 per mile.

$$\left(\frac{33{,}700 \text{ lb coating}}{\text{yr}} + \frac{3{,}370 \text{ lb filter}}{\text{yr}}\right)\left(\frac{\$0.08}{\text{lb}}\right) +$$

$$\left(\frac{200 \text{ miles}}{\text{round trip}}\right)\left(\frac{10 \text{ round trips}}{\text{yr}}\right)\left(\frac{\$1.50}{\text{mile}}\right) = \$6{,}000/\text{yr}$$

[o]Assumes that 81 percent of toluene introduced with the coating and recovered by the adsorber is recovered at a credit of $21,970 for Model Plant A, and an additional credit for MEK recovered of $2,554 for A, based on 73 percent of introduced MEK recovered.[13]

Toluene recovered (Model A) = (0.81)(16.2 lb/h)(1800/hr)($0.93/lb) = $21,970

MEK recovered (Model A) = (0.73)(5.4 lb/h)(1800/hr)($0.36/lb) = $2,554

[p]Assumes reduction of 90 percent of vinyl lacquer emissions (10 percent lost during capture). Assumes reduction of 81 percent of toluene emissions (90 percent capture x 90 percent control in adsorber). Assumes reduction of 73 percent of methyl ethyl ketone emissions (90 percent capture x 90 percent control in adsorber x 90 percent recovery in distillation).

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APPENDIX D

SUMMARY OF INFORMATION GATHERED ON PAPERBOARD COATINGS FOR BLISTER PACKAGING APPLICATIONS

APPENDIX D - SUMMARY OF INFORMATION GATHERED ON PAPERBOARD COATINGS FOR BLISTER PACKAGING APPLICATIONS

D.1 USE OF COMPLIANT COATINGS FOR BLISTER PACKING APPLICATION

Compliant coatings for paperboard used in blister packaging operations are commercially used, although not as widely as in other paperboard coating operations, such as skin packaging.[1,2,3] According to coating vendors, the success of compliant coating for blister pack use is limited because of some disadvantages of the compliant coatings (usually water-based) compared to solvent based coatings, the lack of plant experience with the compliant coatings, and the rarity of environmental regulations for blister pack operations; such regulations encourage the development and use of the compliant coatings.[1,4,5]

Two coating vendors that sell compliant coatings for blister packaging operations were contacted. One vendor stated that their compliant coating contains about 60 percent VOC.[6] The second vendor sells two water-based coatings for blister pack operations that contain 1.1 and 1.9 to 2.2 lb VOC per gallon of coating, excluding water, respectively.[5] Companies using compliant and noncompliant coatings for blister pack applications were contacted; a summary of company and coating vendor experience with compliant coatings for blister pack application follows.

Some differences between water-based and solvent-based coatings require only that plant personnel become accustomed to different operational characteristics. First, water-based coatings do not flow over the paperboard as easily as solvent-based coatings, and the operator must, therefore, become accustomed to a different flowability, or rheology, of the coating[1,2,7] Second, the oven settings must be adjusted to allow for the different drying characteristics of the water-based coating and operation of the oven must be modified accordingly. Specifically, one vendor stated that the air mixture entering the oven must be modified; another vendor stated that, to dry water-based solvents, a multizone oven used to dry solvent based coatings would be modified to a uniform low-temperature single-zone oven.[1,2,7] Third, the use of water-based coatings allows less expensive application roller to be

used, because a special solvent-resistant rubber must be used on rollers contacting solvent-based coatings.[2] An operator would need to get used to the operating characteristics of the new roller type if one were installed.[2]

Other differences between water-based and solvent-based coatings were seen as limitations by some companies or vendors, but not by others. First, some vendors and companies believe the finish of paperboard coated with water-based coating to be less glossy than that coated with solvent-based coatings.[1,2,4,8] Several companies believed the glossiness not to be significantly different.[7,9] Second, paperboards coated with water-based coatings may stick or cling to other boards when stored in stacks.[1,3] Although inconvient, the boards can be separated without problem, and not all users have found the sticking to be a problem.[1,2,10] Third, storage of water-based coated paperboards for many months may weaken the coating so that the blister would not adhere after storage.[1,9,11]

One vendor and a plant both stated that they had no problems with aging, and in fact, had aged boards for 3 or 4 years before laminating them with no problem.[2,10] Fourth, some companies and vendors claim that the production time necessary to seal the blister to the coated paperboard may be longer when water-based solvents are used, thus increasing production time per board.[8,9,11] Other companies and vendors, however, state that the seal times are comparable for both coating bases.[2,10] Table B-1 presents plants listed by the Carded Packaging Institute as coaters of paperboard for blister pack application.[12]

Table B-1. PLANTS COATING PAPERBOARD FOR BLISTER PACKAGING APPLICATION[12]

Company	Address
Card Pak, Inc.	19220 Miles Avenue Cleveland, OH 44128
John D. Clarke & Co., Inc.	1500 Paramount Parkway Batavia, IL 60510
Colonial Packaging Corp.	3150 Clinton Court Norcross, GA 30071
Davis & Henderson, Ltd.	505 Dutton Drive Waterloo, Ontario, N2L 4C8, Canada
Samuel P. Harris, Inc.	55 Pawtucket Avenue Rumford, RI 02916
Jay Printing Co.	Warwick Industrial Drive Warwick, RI 02886
Novel Lithographers	20 Markley Street Port Reading, NJ 07064
Pioneer Paper/Allpax, Inc.	50 Triangle Boulevard Carestadt, NJ 07072
Printpak Industries	I-85 at Road 57 Spartanburg, SC 29304
Robinson Industries, Inc.	P.O. Box 68 Huntley, IL 60142
Rohrer Corp.	P.O. Box 1009 Wadsworth, OH 44281

D.2 REFERENCES

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